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EMERGENCY FUELS TECHNOLOGY

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By

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Different types of engines in the military system require specific fuels for normal operation. Spark-ignition engines require gasoline, compression-ignition engines and ground gas turbine engines require diesel fuel. The requirements of each engine type are listed in Army Regulation 703-1 as primary, alternate and emergency fuels. The work reported here identifies other combustible liquids that, in extreme emergency scenarios, could be

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20. ABSTRACT (Cont'd)

used as field emergency fuels (FEF), either as extenders of the primary fuel supply, or as acquired. Correlations are presented that permit estimating the fuel blend properties considered to be crucial for operation of engines at a minimal performance level.

FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (USAFLRL) located at Southwest Research Institute, San Antonio, TX, under Contract Nos. DAAK70-80-C-0001 and DAAK70-82-C-0001. The Contract Officer's representative was Mr. F.W. Schaekel; Project Technical Monitor was Mr. M.E. LePera, both of DRDME-GL, U.S. Army Mobility Equipment Research & Development Command, Energy and Water Resources Laboratory, Ft. Belvoir, VA.

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I. INTRODUCTION

A. Background

Army Regulation No. 703-1 on "Coal and Petroleum Products Supply and Management Activities" describes the liquid hydrocarbon fuels to be used in Army fuel-consuming materiel and defines them as: (1)*

(1) Primary fuel--A fuel that permits full design performance.

(2) Alternate fuel--A fuel that provides performance equal to the primary fuel but may be a restricted item of supply in tactical areas or has environmental limitations. No degradation of performance or service life occurs as a result of the use of an alternate fuel within the prescribed operational range.

(3) Emergency fuel--A fuel used when the primary or alternate fuel is not available. The use of an emergency fuel may result in increased maintenance and/or reduced engine life. Severe performance derating is permissible when an emergency fuel is used, but it must not destroy the materiel within the operating period prescribed by the engine designer.

AR 703-1 proceeds to list the primary, alternate, and emergency fuels that are permissible for each type of engine. One type of emergency fuel not addressed is that in which a fuel for one type of engine could be blended with fuel for another type to extend the supply. For example, JP-4 could be blended with gasoline to extend the supply of gasoline under an extreme emergency scenario. In addition, other combustible liquids could be used neat or blended with primary fuels. Examples of these are alcohols, hydrocarbon cleaning fluids, fog oil, etc. In this report, the fuels and blends of fuels have been described as field emergency fuels (FEF). Sacrifices in vehicle performance while using FEF are to be expected; however, these fuels would be used only when emergencies exist.

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* Underscored numbers in parentheses refer to the list of references at the end of this report.

B. Purpose

The purpose of this program was to define broadly proposed tolerances that different engines have to degraded/emergency fuel, to suggest blending procedures for extending current primary fuels, and to identify other combustible liquids that could be used as field emergency fuels.

C. Approach

The approach was to identify those specification fuels, solvents, and other combustible liquids that might be found within the military system or in the civilian sector, which could be utilized as field emergency fuels, and to identify and/or develop blending correlations that could ultimately be considered for extending the primary fuel supply.

An "Emergency Fuels Utilization Guidebook" was published by U.S. Department of Energy in 1980 (2) covering the use of a broad spectrum of combustible liquids as emergency fuels. The present work is more restricted in that it addresses fuels and liquids likely to be found in the military system and the suitability of these alternative fuels in military-designed engine systems.

II. FIELD EMERGENCY FUELS

Different types of engines require specific fuels for normal operation, and attempts to operate one type of engine on fuel intended for another engine could result in complete failure. However, some dilution of the primary fuel with another fuel may enable operation with a reduced level of performance. For example, a spark-ignited engine will not operate on diesel fuel, due to its low volatility and low antiknock quality; however, dilution of the gasoline with up to 25 percent diesel fuel would probably provide satisfactory operation of the spark-ignited engine for a limited period. Continued use of this mixture, though, may result in shortened engine life.

Table 1 is a summary of the engine systems currently in use in the Army

TABLE 1. FUEL REQUIREMENTS FOR ARMY MOBILITY ENGINES (AR 703-1)

ENGINE SYSTEM	PRIMARY FUEL	ALTERNATE FUEL	EMERGENCY FUEL	EMERGENCY FUEL BLEND (Suggested)
SPARK-IGNITION: GROUND EQUIPMENT	VV-G-1690(MOGAS) CONUS MIL-G-3056 (MOGAS), F-46 OCONUS	VV-G-1690 (MOGAS) MIL-G-5572 (AVGAS) F-8 F-49 (GASOLINE) F-50 (GASOLINE) ASTM D 439 (GASOLINE) MIL-G-53006 (GASOHOL)		MIL-G-5572 (AVGAS) + MIL-T-5624 (JP-4) MIL-G-5572 (AVGAS) + MIL-G-53006 (GASOHOL) MIL-G-5572 (AVGAS) + VV-G-1690 (MOGAS) VV-G-1690 (MOGAS) + MIL-T-5624 (JP-4) VV-G-1690 (MOGAS) + MIL-T-83133 (JP-8) VV-G-1690 (MOGAS) + MIL-T-5624 (JP-5) VV-G-1690 (MOGAS) + VV-F-800 (DIESEL) VV-G-1690 (MOGAS) + VV-F-815 (FUEL OIL) VV-G-1690 (MOGAS) + PD-680 (DRY CLNG. SOLVENT, I) MIL-G-5572 (AVGAS) + PD-680 (DRY CLNG. SOLVENT, I)
AVIATION EQUIPMENT	MIL-G-5572 (AVGAS), Grade 100/130, F-18	MIL-G-5572 (AVGAS), Grade 115/145, F-22 ASTM D 910 (AVGAS)		
GAS TURBINE: GROUND EQUIPMENT	VV-F-800 (DF-2), F-54	MIL-T-5624 (JP-4, JP-5), F-40, F-44 MIL-T-83133 (JP-8), F-34 MIL-F-815 (FO-1 & FO-2) F-75 (NAVY DISTILLATE) ASTM D 975 (DIESEL) ASTM D 3699 (KEROSENE) ASTM D 1655 (AVIATION FUEL) ASTM D 2880 (GAS TURBINE FUEL) ASTM D 396 (FUEL OIL, NO. 1 & 2)	MIL-G-3056 (MOGAS), F-46 MIL-G-5572 (AVGAS), F-18 VV-G-1690 (MOGAS) MIL-G-53006 (GASOHOL) F-49 (GASOLINE) F-50 (GASOLINE)	
AVIATION EQUIPMENT	MIL-T-5624 (JP-4), F-40	MIL-T-83133 (JP-8), F-34 MIL-T-5624 (JP-5), F-44 ASTM D 1655 (AVIATION FUEL)		

TABLE 1. FUEL REQUIREMENTS FOR ARMY MOBILITY ENGINES (AR 703-1) - CONTINUED

ENGINE SYSTEM	PRIMARY FUEL	ALTERNATE FUEL	EMERGENCY FUEL	EMERGENCY FUEL BLENDS (SUGGESTED)
COMPRESSION-IGNITION: GROUND EQUIPMENT TWO-CYCLE AND FOUR-CYCLE, NA(2) & TURBOCHARGED ENGINES	VV-F-800 (DF-2), F-54(1)	MIL-T-5624 (JP-5), F-44	MIL-T-83133 (JP-8), F-34	MIL-T-5624 (JP-4) + VV-F-800 (DIESEL)
		ASTM D 975 (1-D & 2-D DIESEL)	MIL-F-16884 (DFM), F-76	PD-680 (T-I) + VV-F-800 (DIESEL)
			F-75 (NAVY DISTILLATE)	PD-680 (T-II) + VV-F-800 (DIESEL)
			VV-F-815 (FO-1 & FO-2)	MIL-T-5624 (JP-4) + MIL-T-83133 (JP-8)
			MIL-T-5624 (JP-4), F-40	MIL-T-5624(JP-4) + MIL-T-5624 (JP-5)
			ASTM D 2880 (TURBINE FUEL)	VV-F-815 (NO.4) + VV-F-800 (DIESEL)
			ASTM D 3699 (KEROSENE)	VV-F-815 (NO.4) + MIL-T-5624 (JP-4)
			ASTM D 1655 (AVIATION FUEL)	VV-F-815 (NO.4) + MIL-T-83133 (JP-8)
			ASTM D 396 (FO-1 & FO-2)	VV-F-815 (NO.1) + VV-F-815 (NO.4)
			ASTM D 975 (4-D DIESEL)	VV-F-800 (DIESEL) + MIL-F-12070 (FOG OIL)
				MIL-T-5624 (JP-4) + MIL-F-12070 (FOG OIL)
				ASTM D 3699 (KEROSENE) + MIL-F-12070 (FOG OIL)
				MIL-T-5624 (JP-4) + MIL-H-5606 (HY. FLD.)
				MIL-T-83133 (JP-8) + MIL-H-5606 (HY. FLD.)
				VV-F-800 (DIESEL) + MIL-H-5606 (HY. FLD.)
FOUR-CYCLE, MAN(3) SYSTEM (MULTIFUEL) (4)	VV-F-800 DF-2), F-54	MIL-T-5624 (JP-4, JP-5), F-40, F-44 MIL-T-83133 (JP-8), F-34 MIL-F-16884 (DFM), F-76 F-75 (NAVY DISTILLATE) MIL-G-3056 (MOGAS), F-46 F-50 (GASOLINE) ASTM D 3699 (KEROSENE) ASTM D 1655 (AVIATION FUEL) ASTM D 2880 (TURBINE FUEL) ASTM D 975 (DIESEL)	VV-F-815 (FO-1 & FO-2) VV-G-1690 LIMITED GRADE (MOGAS) ASTM D 439, ANTIKNOCK INDICES 87 & 89 (GASOLINE)	

(1) F-54 IS INTENDED FOR OCONUS USE. WITHIN CONUS, GRADES DF-A, DF-1, AND DF-2 (CONUS) APPLY.
(2) NORMALLY-ASPIRATED.
(3) MACHINENFABRIK AUSBURG-NURNBERG, AG
(4) ENGINES POWERING 2-1/2-T AND 5-T TRUCK SERIES.

and the respective fuels currently in or proposed for inclusion in AR 703-1 as primary, alternate, and emergency fuels. The table, with the exception of the column headed "Emergency Fuel Blends," is found in Table 2-1 of the current revision of AR 703-1(3).

A. FEF for Gasoline-Consuming Ground Engines

The spark-ignition (SI) engine requires a fuel that can be easily vaporized and mixed with air in the carburetor before it is introduced into the combustion chamber. There, the air-fuel mixture is ignited by a spark, and the resulting combustion products expand to force the piston out, thus creating power. The combustion products are exhausted during the return stroke of the piston.

1. Limiting Fuel Properties for Emergency Engine Operation

Estimated minimum fuel properties that would permit reduced performance operation of spark-ignited engines are shown in Table 2. The logic for

TABLE 2. PROPOSED CRUCIAL PROPERTIES FOR SPARK-IGNITED ENGINE OPERATION ON FIELD EMERGENCY FUEL

Property	ASTM Method	FEF Crucial Requirement*	MIL-G-3056D Requirement
Distillation, °C	D 86		
10% Evaporated		120 max	50 to 70
50% Evaporated		-	80 to 115
90% Evaporated		300 max	132 to 180
Reid Vapor Pressure, psi	D 323	2 min	7 to 9
Research Octane Number	D 2699	50 min	91.0 min
Motor Octane Number	D 2700	45 min	83.0 min

*Estimated values based on work performed at AFLRL and reported in AFLRL Interim Report No. 60, "Performance of Diesel and Turbine Engine Fuels in a Military Spark Ignition Engine."(4)

suggesting these limits is discussed below. One additional requirement not shown in the table is that the fuel should be free of sediment and water.

2. Extenders for Gasoline

The primary fuel for spark-ignited, ground equipment engines as designated by AR 703-1 and shown in Table 1 is MIL-G-3056 (MOGAS), NATO F-46 for OCONUS and VV-G-1690 (MOGAS) for CONUS. Alternate fuels are all gasolines listed as VV-G-1690, ASTM D 439, F-49, F-50, AVGAS MIL-G-5572 (F-42) and MIL-G-53006 (GASOHOL). No emergency fuels are listed; however, commercially available blends of gasoline and up to 20 percent ethanol or methanol should be considered as emergency fuels for SI engines.

Work at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL) reported in Interim Report No. 60, "Performance of Diesel and Turbine Fuels in a Military Spark Ignition Engine," indicates that the L-141 engine (currently powering the M-151 vehicle) could be operated on neat JP-4, although at substantially reduced output. A 50-percent blend of Jet A fuel in gasoline was the maximum feasible gasoline dilution that the L-141 engine would tolerate and a 50-percent blend of diesel fuel DF-2 in gasoline was also found to be the maximum dilution limit for the L-141 engine.(4) These conclusions are based on engine dynamometer testing rather than vehicle testing. Octane numbers for these blends were not reported; however, in the current work, similar blends of gasoline with JP-4, Jet A, and DF-2 fuels were measured for octane numbers. The CFR octane engine, as presently configured, does not permit the measurement of octane numbers below 60; therefore, dilution of the test fuel with isooctane and extrapolation of the obtained values can be used to estimate these low octane numbers. This technique was used to determine the octane numbers for the DF-2, Jet A, JP-4 samples, and blends shown in Table 3. The research and motor octane numbers for blends of gasoline with the different fuels are plotted in Figures 1 through 4. The lines represent expected values if the octane numbers for the different fuels were additive. The experimental data points shown on the plots are on the lines in some cases and deviate from the anticipated

TABLE 3. PROPERTIES OF GASOLINE EXTENDED WITH JP-4, JET A AND DF-2

AL Number	Gasoline 10937-G	JP-4 9254-T	JP-4 10583-T	Jet A 10582-F	DF-2 10697-F	Blend 1 10951-F	Blend 2 10952-F	Blend 3 10953-F	Blend 4 10954-F	Blend 5 10955-F	Blend 6 10956-F	Blend 7 10957-F
Composition, vol%												
Gasoline, AL-10937-G	100	0	0	0	0	75	50	75	50	75	50	75
JP-4, AL-9254-T	0	100	0	0	0	25	50	0	0	0	0	0
JP-4, AL-10583-T	0	0	100	0	0	0	0	25	50	0	0	0
Jet A, AL-10582-T	0	0	0	100	0	0	0	0	0	25	50	0
DF-2, AL-10697-F	0	0	0	0	100	0	0	0	0	0	0	25
Properties												
D 86 Distillation, °C												
IBP	28	58	58	183	199	34	38	33	39	33	34	33
10% Recovered	61	90	91	194	238	71	77	67	80	70	86	64
20% Recovered	82	101	104	201	249	90	92	87	96	96	112	89
50% Recovered	110	136	149	213	272	116	121	114	122	127	175	120
90% Recovered	159	194	229	241	322	174	183	192	216	217	231	282
EP	213	238	255	264	355	223	232	255	263	259	259	328
Residue, vol%	0.5	1.5	1.5	1.5	2.0	1.5	1.5	1.0	0.5	1.0	1.5	1.0
Loss, vol%	0	0	0	0	0	0.5	0.5	1.0	0	1.0	1.0	1.0
Reid Vapor Pressure, psi	8.9	2.9	2.1	0	0	6.9	5.6	7.1	5.7	6.8	5.1	7.3
Research Octane Number (RON)	98.0	52.5	46.2	25.0	32.4	86.2	79.0	85.2	70.0	80.1	61.0	81.9
Motor Octane Number (MON)	88.8	44.0	39.6	21.2	15.5	81.7	60.0	81.2	59.0	64.0	47.0	65.0
(R+M)/2	93.4	48.2	42.9	23.1	24.0	84.0	69.5	83.2	64.5	72.1	54.0	73.5

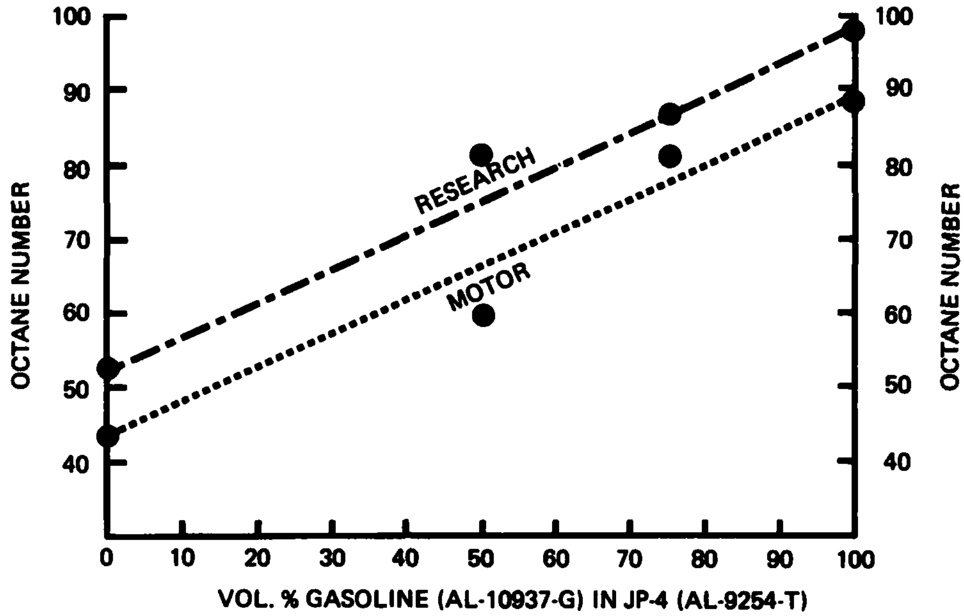


FIGURE 1. OCTANE NUMBERS OF JP-4 (AL-9254-T) AND GASOLINE (AL-10937-G) BLENDS

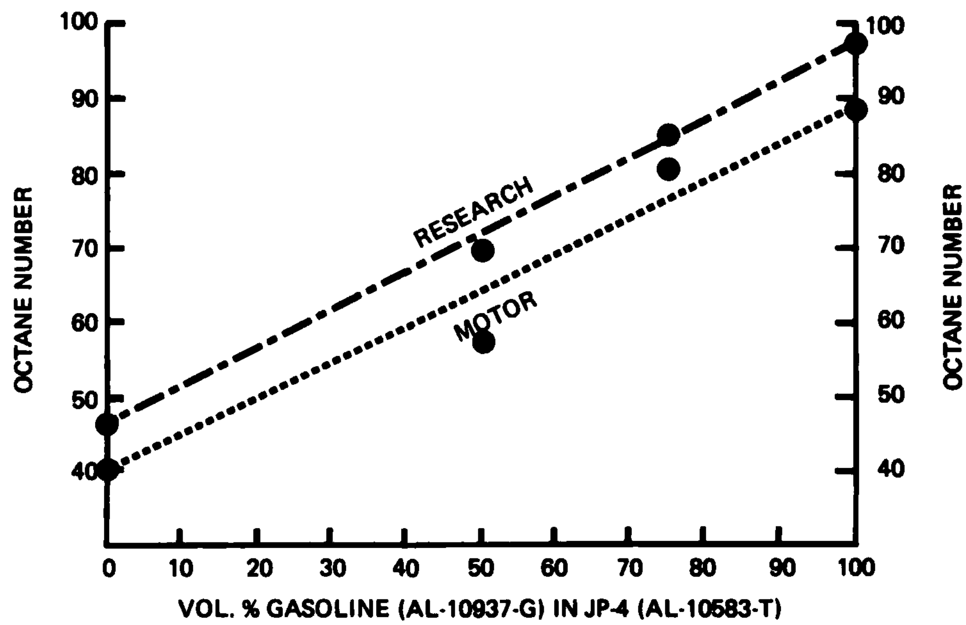


FIGURE 2. OCTANE NUMBERS OF JP-4 (AL-10583-T) AND GASOLINE (AL-10937-G) BLENDS

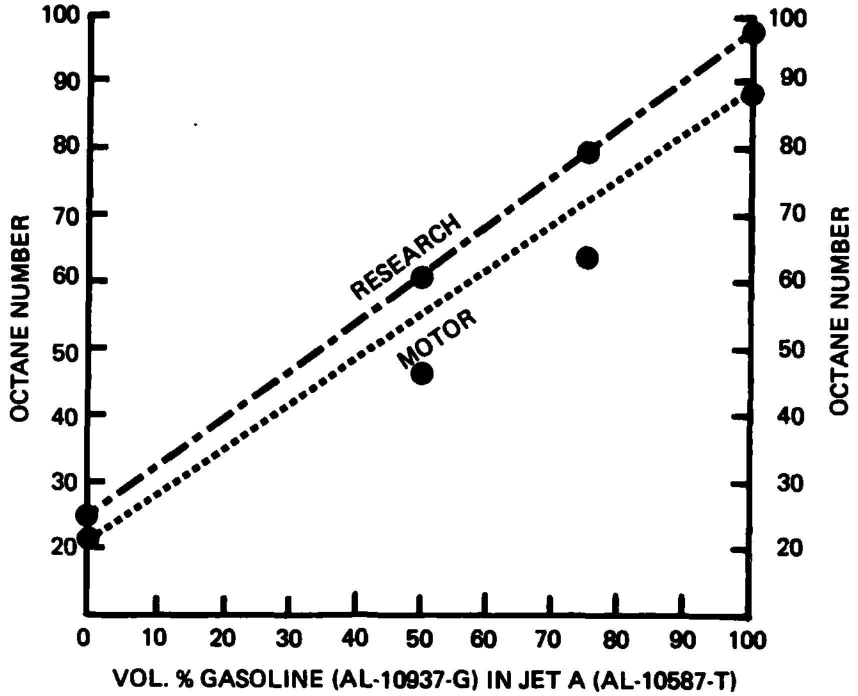


FIGURE 3. OCTANE NUMBERS OF JET A (AL-10582-T) AND GASOLINE (AL-10937-G) BLENDS

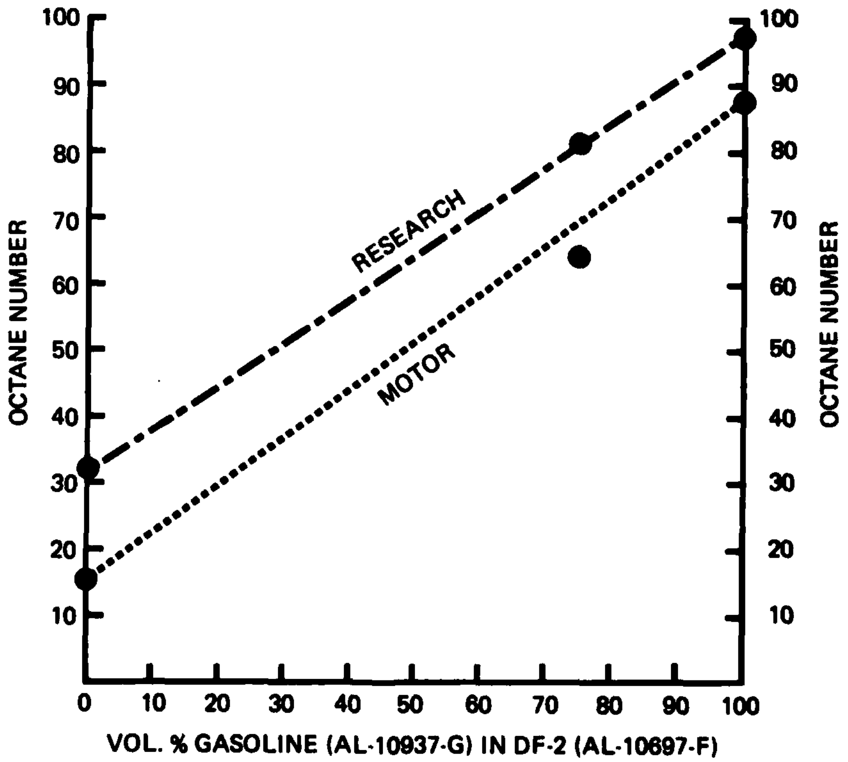


FIGURE 4. OCTANE NUMBERS OF DF-2 (AL-10697-F) AND GASOLINE (AL-10937-G) BLENDS

values in others. The accuracy of the procedure used for estimating low octane values is certainly less than if direct measurements could be made.

These data show that the neat JP-4 samples had research octane numbers in the neighborhood of 50, and 50 percent blends of both Jet A and DF-2 in gasoline had values slightly above 50. In the work with the L-141 engine referred to earlier, neat JP-4, and 50/50 blends of either DF-2 or Jet A with gasoline operated the engine with considerably reduced power output. The conclusion from these observations would seem to be that L-141 engines can be operated in an emergency with fuels of about 50 research octane number. However, this approximation may not hold for other spark-ignition engines within the vehicle/equipment inventories.

The measured Reid vapor pressures for the blends shown in Table 3 tend to indicate that they would be adequate for starting spark-ignition engines under mild to hot ambient conditions. However, these engines may not start with these fuel blends in cold winter ambient conditions. The distillation temperature data shown in Table 3 for the blends at the 10- and 50-percent recovered point indicate that driveability of vehicles utilizing these fuel blends would probably be very poor, especially during warm-up. Extensive use of these blends could result in crankcase oil fuel dilution which would reduce the lubrication quality of the oil. Spark plug fouling due to carbon buildup on the electrodes would necessitate maintenance attention for continued engine operation.

JP-5 and a Stoddard solvent were blended with gasoline, and the blends were evaluated for distillation, vapor pressure, and octane numbers. The values obtained are shown in Table 4, and are similar to those obtained for the blends of gasoline with Jet A and DF-2. Blends 1 and 3 in Table 4, both of which contained 50 percent gasoline with JP-5 and Stoddard solvent, respectively, had research and motor octane numbers which were virtually the same. This similarity was unexpected, and may be attributed to the difficulty in measuring octane numbers of 65 and below.

It should be noted that blending of gasolines with DF-2, Jet A, or kero-

TABLE 4. PROPERTIES OF GASOLINE EXTENDED WITH JP-5 AND STODDARD SOLVENT

(AL Number)	Gasoline (10937-G)	JP-5 (7247-F)	Stoddard Solvent	Blend 1 (11060-G)	Blend 2 (11061-G)	Blend 3 (11062-G)	Blend 4 (11063-G)
Gasoline, (AL-10937-G), vol%	100	0	0	50	75	50	75
JP-5, (AL-9247-F), vol%	0	100	0	50	25	50	25
Stoddard Solvent, vol%	0	0	100	0	0	0	0
Properties							
D 86 Distillation, °C							
IBP	28	179	163	34	28	32	24
10% evaporated	61	199	167	89	68	89	67
20% evaporated	82	205	168	113	95	116	94
50% evaporated	110	218	173	177	127	152	126
90% evaporated	159	246	186	236	223	181	177
EP	213	266	221	259	254	208	208
Residue, vol%	0.5	1.0	1	1.5	1	1	1
Loss, vol%	0	0	0	0	0	0	0
Reid vapor pressure, psi	8.9	0	0	5.3	7.0	4.5	6.8
RON	98.0	-*	-	63.5	82.0	62.2	81.4
MON	88.8	-	-	63.6	78.7	61.1	78.3
(R+M)/2	93.4	-	-	63.6	80.4	61.6	79.8

* Not determined

sene-type fuels creates more hazardous fuel mixtures than do the individual fuels. Due to the vapor pressures of the respective fuels at ambient temperatures, gasoline produces a vapor-air mixture in the ullage of a container that is fuel rich and above the flammability limits; diesel fuels and kerosenes produce mixtures that are fuel lean and below flammability limits; but a broad range of concentration mixtures of the two are likely to produce flammable vapor-air mixtures at ambient temperatures.

Most of the blends listed as emergency fuel blends for spark-ignited engines in Table 1 have been investigated in this program. Those blends not addressed in the experimental program are those containing AVGAS, gasohol, fuel oil, and JP-8. AVGAS will behave no differently than MOGAS when blended with JP-4, JP-5, Jet A, or diesel fuel. Gasohol could be blended with AVGAS as suggested; however, both fuels could be used without blending as alternate or emergency fuels. Caution should be used when blending gasohol with other fuels, even gasoline, because a change in the hydrocarbon-type content of the fuel could cause phase separation if a small concentration of water is present. A small batch should first be evaluated for compatibility by visual appearance for no phase separation. Methanol is not listed in Table 1 as a component for emergency blends; however, up to 10 percent by volume of methanol could be added to gasolines for extending the supply. As with gasohol, the presence of very small amounts of water can cause phase separation in methanol/gasoline blends.

The fuel properties identified in Table 2 as being crucial for spark-ignited engine operation can be estimated if the properties of the two components of a gasoline-extender blend are known.

The Reid vapor pressure is a property that blends almost linearly; therefore, the vapor pressure of a gasoline and JP-5 blend, for example, can be readily estimated. The distillation characteristics of a blend of two such diverse components as gasoline and diesel fuel or gasoline and JP-5 cannot be estimated. If these values are needed, it is best to determine the distillation in the laboratory. A discussion of this subject appears later in this report. Octane rating also has a blending relationship that is ap-

proximately linear; therefore, the octane ratings for any blend can be estimated if the ratings for the components are known.

It may be desirable to know several other properties for blends of gasoline and other fuels, for example, sulfur content, aromatic content, gravity (API or specific), or lead content. All these properties, except API gravity, have a linear blending relationship. Specific gravity, as opposed to API gravity, has a linear blending relationship.

The emergency fuel blends for spark-ignition engines listed in Table 1 can be grouped into two areas: (1) blends of similar volatility fuels and (2) blends of different volatility fuels. Blends of AVGAS with MOGAS, gasohol, or JP-4 should result in fuels with adequate octane values, distillation range, and vapor pressure to ensure satisfactory operation of the spark-ignition engines. Octane ratings of the AVGAS, MOGAS, and gasohol blends should provide adequate octane ratings when blended in any proportion, since all have high octane ratings. JP-4, however, has a low octane rating; therefore, almost any amount of JP-4 in gasoline will produce engine knock and reduced performance, as demonstrated in Figures 1 and 2.

Dissimilar fuel blends are blends of MOGAS or AVGAS with diesel fuel, Jet A, JP-5, burner fuel oil, and/or dry cleaning solvent (which is similar to kerosene). The crucial properties listed in Table 2 are greatly affected by these types of blends, as shown in Figures 3 and 4. The properties listed in Table 3 for blends of dissimilar fuels indicate that 50-percent blends are probably the limit for marginal engine operation.

In Figure 5, the effect of blending gasoline (9 lb RVP) with JP-4, Jet A or DF-2 on the Reid vapor pressure is demonstrated.

3. Substitute Fuels

The alternate fuels listed in Table 1 for spark-ignition engine systems are in reality the only substitute fuels that may be available in a field emergency scenario. Many combustible liquids could be thought of as adequate

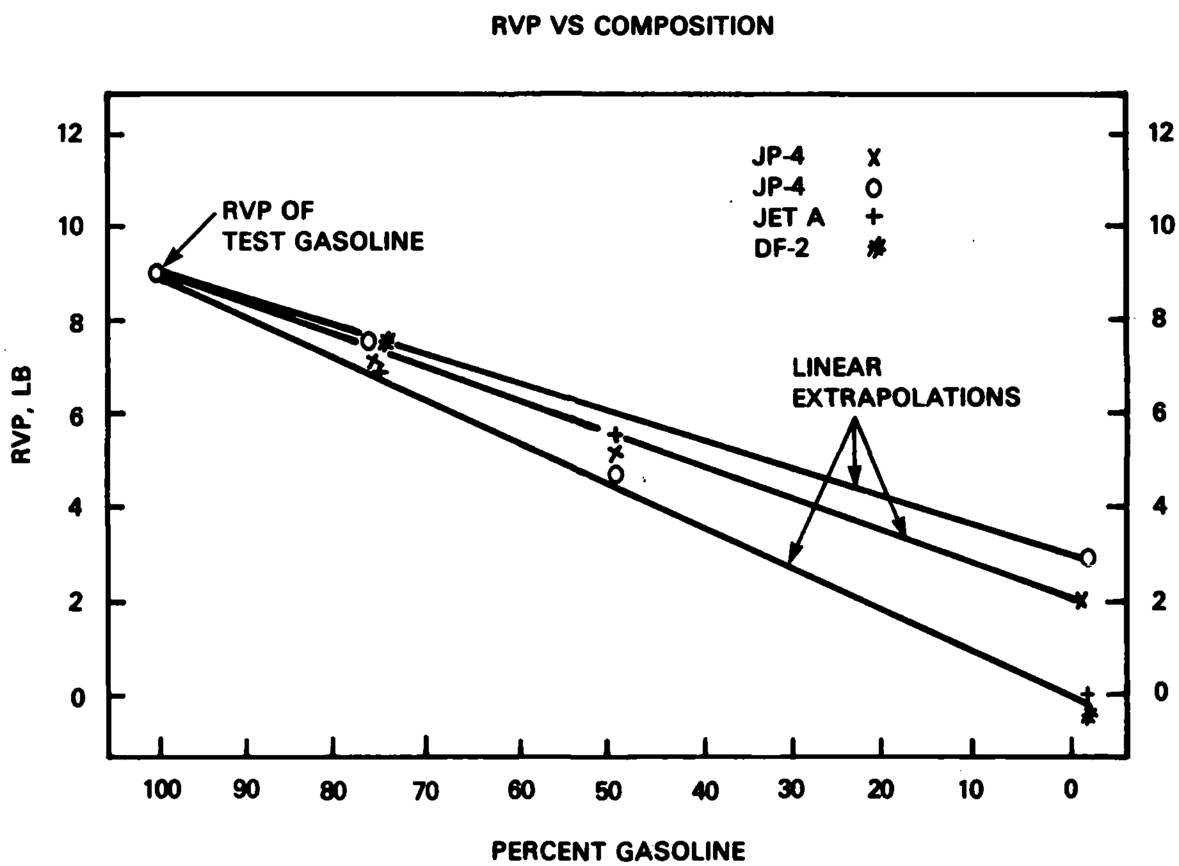


FIGURE 5. RVP OF GASOLINE BLENDED WITH
JP-4, JET A AND DF-2

field emergency fuels for spark-ignited engines; however, due to the carburetion system in these engines, these materials will not permit operation. Examples are ethanol and methanol, which are excellent gasoline extenders, and operate quite well in engines with carburetion systems designed for their specific use. There are no quick retrofit systems for changing a gasoline-burning engine to a methanol- or ethanol-burning one.

A byproduct of the oats industry, furfural, which is a combustible liquid, was investigated at AFLRL as a possible fuel extender or substitute fuel.(5) Due to its low octane and cetane ratings, high viscosity, and low net heat of combustion, it was concluded that furfural is not acceptable as a mobility fuel and is not a particularly good fuel extender.

B. FEF for Diesel-Consuming Engines

Compression-ignition (CI) engines, more commonly referred to as diesel engines, are high-compression, self-ignition engines in which the fuel is ignited by the heat of compression, and no spark plug is used. The cycle consists of charging the combustion chamber with air, compressing the air, injecting the fuel which ignites spontaneously, expanding the burned gases, and exhausting products of combustion.

The compression ignition engines can be designed to operate on a four- or a two-stroke cycle. The four-stroke cycle has better volumetric efficiency, good combustion characteristics, and positive exhaust gas scavenging, while the two-stroke cycle has the advantage of compactness in relation to power output.

Both types of compression-ignition engines are found in the U.S. Army's vehicle fleet. A variation of the four-stroke cycle engine with a divided combustion chamber is common in the military vehicle fleet. The system developed by Machinenfabrik Ausburg-Nurnberg, AG (MAN) permits this engine to use a wide range of fuels; therefore, it is designated a multifuel engine. Field emergency fuel for the multifuel engines is discussed in a later section.

1. Limiting Fuel Properties for Emergency CI Engine Operation

The cetane number of a fuel is the numerical result of a special laboratory engine test designed to evaluate the ignition delay of a fuel. Hydrocarbon composition and physical characteristics may cause a fuel to have a number of ignition points within the combustion chamber, resulting in uncontrolled rapid pressure rise. Thus, it is desirable to minimize ignition delay. The cetane number scale was developed so that a fuel with a short ignition delay has a high cetane number. This fuel property affects engine performance factors such as ease of starting, warmup, combustion roughness, acceleration, deposits, and exhaust smoke. Other properties of compression-ignition fuels considered to be crucial for engine operation are distillation, viscosity, and cloud point. Carbon residue, and sulfur content are other properties of secondary importance with respect to field emergency operation.

Diesel engine manufacturers provide fuel specifications for their production engines, and Ashland Oil Company periodically publishes a compilation of those requirements under the title, "Fuel and Lubricants Specification Book".(6) Table 5 summarizes the limits for fuel distillation, cetane number, viscosity at 100°F, sulfur content, and carbon residue requirements as specified by several diesel engine manufacturers.

As part of a recent project at AFLRL, the performances of four different compression-ignition engines were evaluated on 18 test fuels with a wide range of properties as shown in Table 6.(7) The engines were representative of two-cycle, four-cycle direct injection, four-cycle indirect injection, and the MAN combustion system. All the engine performances were affected to some degree by the range of properties, but not severely enough to halt operation. The cetane numbers, ranging from 31 to 53, did not significantly affect the performance of any of the engines, indicating that all of the test fuels had high enough cetane numbers for adequate operation at the ambient conditions encountered during the tests. No cold start tests were made in this evaluation.

Based on the above work and information from engine manufacturers, it is

TABLE 5. FUEL REQUIREMENTS AS SPECIFIED BY DIESEL ENGINE MANUFACTURERS*

	90% Distillation, °F	Cetane No.	Viscosity cSt, at 100°F	Sulfur Content, wt% max	Carbon Residue, wt% max
Alco Power, Inc.	675 max	40 min	1.8-5.8	1.0	0.35
Allis-Chalmers Manufacturing	640 max	40 min	1.4-5.8	0.5	0.35
Caterpillar Tractor Co.	540-640	35 min(a) 40 min(b)	1.9-4.1	0.4	0.35
Chicago Pneumatic Tool Co.		40 min	2.7-1.3	0.5	
Cooper-Bessemer Co. #1-D	550 max	40 min	1.4-2.5	0.5	0.15
#2-D	640 max	40 min	2.0-4.3	0.5	0.35
Cooper Energy Services	675 max	35-50	2.7-7.4	1.0	
Cummins Engine Co.	675 max	40 min	1.4-5.8	1.0	0.25
Detroit Diesel-Allison Division, 2-D	640 max	40 min	1.9-4.1	0.5	
Deutz Corporation (Air-Cooled Engines)		45 min		0.5	
Dresser Industries			7.4-20.5	2.0	
General Motors Corporation	650 max	40 min	1.8-5.8	0.5	0.35
Fairbanks Morse Engine Div. (Colt Industries)	675 max	45 min	1.8-7.4	0.5	0.35
Fulton Iron Works Co. (Straight Diesel)	735 max	35 min	2.1-15.7	1.0	1.5
Gardner Diesel Engines	675 max		5.5 max	0.4	
John Deere	- - - - - - - - - - - - - - - - ASTM Requirements - - - - - - - - - - - - - - - -				
Ingersoll-Rand Co.		40 min	15.7 max	1.0	0.5
Kahlenberg Brothers Co.	525-615 max	45 min	1.8-5.8	1.0	0.2
Lister Diesel, Inc.	650 max	45 min	2.0 min	1.0	0.2
Mack Trucks		45 min	2.4-4.0	0.5	0.25
Massey-Ferguson Inc. #1-D	550 max	40 min	2.5 max	0.5	0.15
#2-D	540-640	40 min	2-4.3	0.5	0.35
#4-D		30 min	5.8-26.4	2.0	
Murphy Diesel Co.		45 min	2.7 min	0.5	0.20
Waukesha Engine Co.	657 max	40 min	1.7-7.4	0.7	0.25
White Engines	675 max	45 min	1.8-4.9	0.5	0.30

* Data taken from "1980 Fuel and Lubricant Specification Book" published by Ashland Oil Company.(6)
(a) Precombustion chamber engines.
(b) Direct injection engines.

TABLE 6. RANGE OF PROPERTIES FOR EIGHTEEN TEST FUELS

	High	Low
Cetane No.	53	31
Gravity, °API	54.0	37.1
Specific Gravity, g/mL at 15.6°C	0.8718	0.7628
Distillation, D 86, °C		
10% recovered	241	91
50% recovered	287	149
90% recovered	367	217
Viscosity at 40°C, cSt	3.55	0.78
Aromatics, vol%	61.6	12.9
Net Heat of Combustion, MJ/kg	43.838	41.913
Btu/lb	18,847	18,041

estimated that the limits for field emergency fuels to operate a compression ignition engine would be as shown in Table 7. Property limits for VV-F-800C (diesel fuel grade DF-2) are also shown. The field emergency fuel should be free of visible solids that could potentially plug filters in the engine system and restrict the flow of fuel to the engine.

2. Extenders for Diesel Fuel and Properties of Blends

Several hydrocarbon-based products are in the military supply system that could be used as field emergency fuels neat or blended with available diesel fuel. A list of such products follows: JP-4; JP-8; VV-F-815-D Nos. 1,2 and 4 Fuel Oils; PD-680 Type II, dry cleaning solvent; commercial kerosene; MIL-F-12070A, fog oil; and MIL-H-5606, hydraulic fluid. JP-5 is an alternate fuel to DF-2 for use in compression-ignition engines. Blends such as JP-4 in diesel fuel may produce vapor-air mixtures which are likely to be within flammable limits at ambient temperatures; therefore, these blends should be prepared and used with extreme caution.

TABLE 7. PROPOSED CRUCIAL PROPERTIES FOR COMPRESSION IGNITION ENGINE OPERATION ON FIELD EMERGENCY FUEL

Property	FEF Crucial Requirement	VV-F-800C DF-2 Requirement
Distillation, °C (°F)		
10%	80 - 250 (176-482)	NR*
50%	130 - 300 (266-572)	Report
90%	385 (725) max	338 (640) max
EP	400 (752) max	370 (698) max
Cetane Number	35 min	45 min
Kin. Visc. at 40°C	1.1 to 9.0	1.0 to 4.1
Cloud point, °C (°F)	Below prevailing ambient temp	Below prevailing ambient temp

*NR = No Requirement

Lubricating oil could be used in limited amounts to blend with diesel fuel for extending the supply of fuel. An engine manufacturer suggests that such a fuel oil/lube oil blend could be used, provided the viscosity of the final emergency fuel mixture falls within a viscosity range of 1.2 to 13.1 cSt at 40°C.(8) The example in their technical bulletin shows that as much as 70 percent by volume of a SAE 30 grade lubricating oil could be blended with a fuel having a kinematic viscosity of 1.3 cSt at 40°C and the resulting blend would have a viscosity of about 13 cSt. A maximum recommended viscosity of 6 cSt at 40°C is indicated on the chart which corresponds to a blend of approximately 55 percent lubricating oil and 35 percent fuel.

When blending JP-4 with DF-2 to extend the supply of DF-2, it is desirable to anticipate the properties of the resulting fuel. Therefore, properties of various blends of two different JP-4's in a DF-2 (Cat 1-H reference diesel fuel used for engine oil qualification tests 1-G and 1-H, which are conducted in a single-cylinder Caterpillar Tractor Company engine) have been determined and are listed in Table 8. From these data, existing fuel blend property estimations have been verified for cetane index, cetane number, API gravity, 10-percent distillation, and kinematic viscosity at 40°C.

TABLE 8. PROPERTIES OF DF-2 AND JP-4 FUELS AND THEIR BLENDS

Fuel or Blend Number	DF-2	JP-4	JP-4	1	2	3	4	5	6
Composition, vol%									
AL-10115-F, DF-2 (Cat 1-H)	100	0	0	75	50	25	75	50	25
AL-9254-T, JP-4	0	100	0	25	50	75	0	0	0
AL-10583-T, JP-4	0	0	100	0	0	0	25	50	75
Property									
Gravity °API	34.9	56.4	54.0	39.4	44.6	50.4	39.0	43.6	48.3
Specific Gravity at 15/15°C	0.8504	0.7531	0.7628	0.8280	0.8035	0.7779	0.8299	0.8081	0.7870
Viscosity at 40°C, cSt	3.12	0.71	0.78	1.97	1.32	0.93	2.08	1.44	1.04
Cetane Number	53.0	33.0	34.5	47.2	43.8	39.4	48.3	44.6	40.3
Cetane Index	48.0	30.9	34.7	53.5	49.8	32.6	52.5	53.3	45.4
Cloud Point, °C	-4	-57	-60	0	-5	-9	1	-4	-14
Pour Point, °C	-15	-70	-62	-18	-21	-34	-15	-23	-33
Flash Point, °C	80	*	*	-20	-25	-29	-12	-25	-35
Distillation, D 86, °C									
IBP	194	58	58	80	70	59	82	74	67
10% recovered	241	90	91	137	111	94	143	109	99
20% recovered	253	101	104	186	133	111	208	137	117
50% recovered	272	136	149	262	217	159	262	233	190
90% recovered	316	194	229	312	301	278	312	298	273
EP	355	238	256	354	341	328	349	341	331
Residue, vol%	1	1.5	1.5	1.5	1	1.5	1.5	1.5	1.0
Loss, vol%	0	0	0	0	0	0	0	0	0

*Could not be determined, <-30°C

a. Cetane Index

The cetane index of a blend can be estimated by adding proportionally by volume the calculated cetane index of the individual components. The estimates for the six blends in Table 8, the D 976 calculated cetane indices, and the measured cetane number are compared below:

	Predicted Cetane Index		
Blend Number	By Proportionate Addition of Indices	By D 976 calculation	Measured Cetane Number D 613
1	43.5	53.5	47.2
2	39.4	49.8	43.8
3	35.2	32.6	39.4
4	44.7	52.5	48.3
5	41.4	53.3	44.6
6	38.0	45.4	40.3

The proportionate addition of cetane indices gives conservative values that are from 2 to 4 numbers below the measured cetane numbers. It should be noted that the DF-2 fuel used in these blends had a cetane index that was 5 numbers below the measured cetane number. Unexpectedly, the cetane indices and cetane numbers of the two JP-4 fuels in Table 8 were in good agreement. The D 976 calculated cetane indices of the blends listed above are far too high and in poor agreement with measured cetane numbers.

These data indicate that the techniques for estimation of cetane indices of DF-2 and JP-4 blends investigated here are not reliable; however, those predicted by proportionate addition of indices may serve as a conservative guess.

b. Cetane Number

The cetane number of a blend may be estimated by plotting the cetane number (when known) of each component linearly by volume. This is shown in Figure

6, where the line on the graph represents the predicted cetane number at any given component percentage, and the points indicate experimental values of actual blends. It is not normal practice to determine cetane numbers on turbine or burner fuels since the specifications for these fuels do not require cetane number.

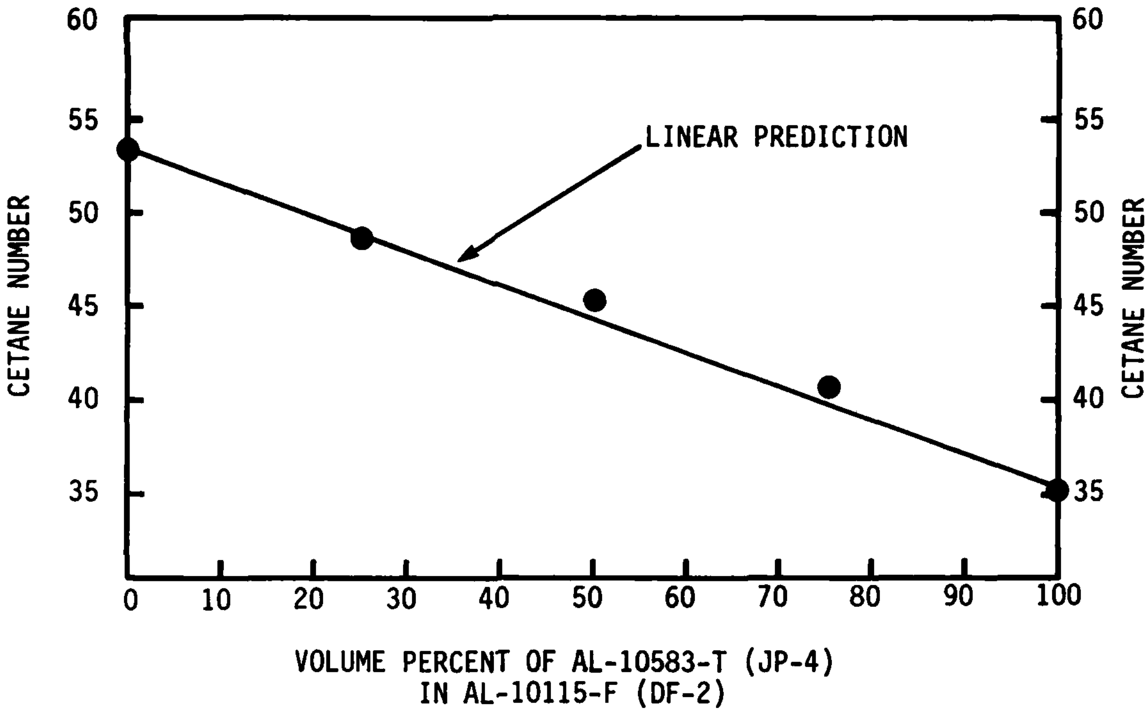
c. API Gravity and Specific Gravity

Both the API gravity and specific gravity of a blend may be estimated by plotting each quantity linearly by volume. Figures 7 and 8 represent those predictions. As before, the line on the graph represents the predicted gravity of a blend at any given component percentage, and the points indicate experimental values of actual blends. The data points for API Gravity in Figure 7 are not on the curve, indicating that this property does not blend linearly. The relationship between these two gravity scales is shown in Figure 9. The non-linearity of the API gravity scale as the specific gravity decreases is apparent.

d. 10-Percent Distillation Temperature

The 10-percent distillation temperature of a blend of widely different boiling range fuels such as JP-4 and DF-2, as shown in Figure 10, cannot be linearly predicted by plotting the 10-percent distillation points of the components. However, when the blend components are of similar boiling ranges, such as a gasoline and a light naphtha, the distillation characteristics of the blend can be approximated by averaging the material boiling off at a given temperature in the ratio of the quantity of each blending component.(9) An example is a naphtha containing 18 percent of material boiling off at 93°C and a natural gasoline containing 70 percent of material boiling off at 93°C. If the two stocks are blended: 20 volumes of natural gasoline to 80 volumes of naphtha, the amount of the blend that will distill at 93°C can be calculated.

$$0.80 \times 18 = 14.4$$
$$0.20 \times 70 = \underline{14.0}$$
$$\text{Material boiling off at } 93°\text{C} = 28.4$$



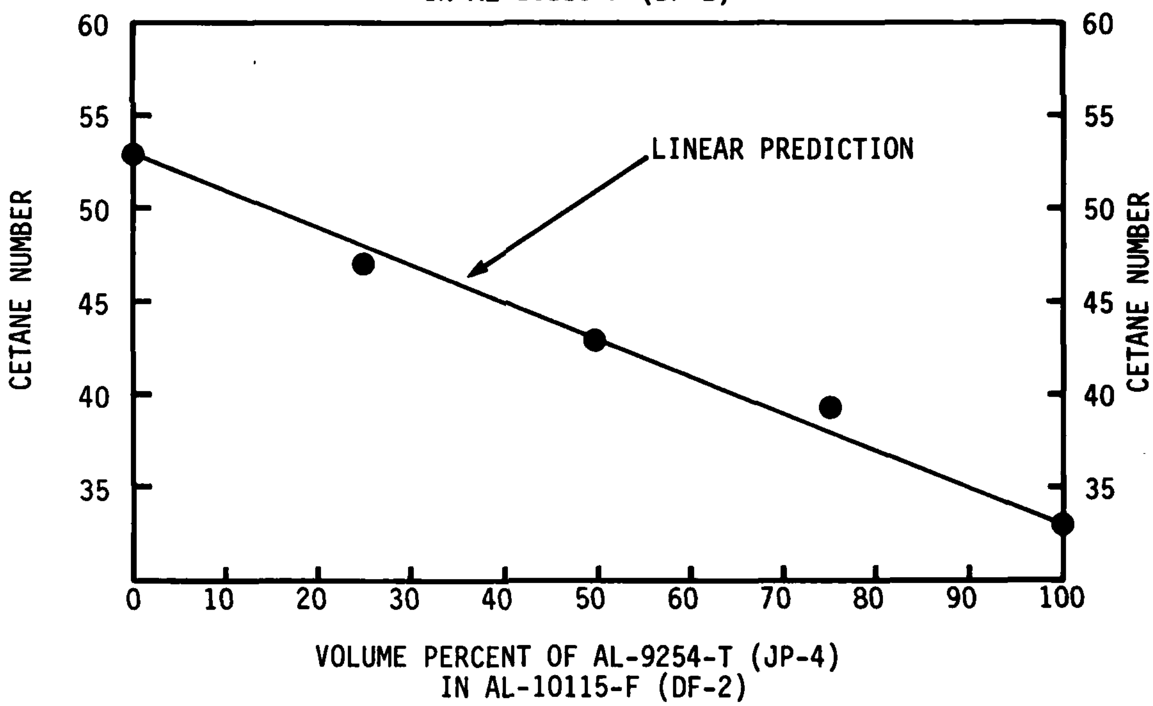
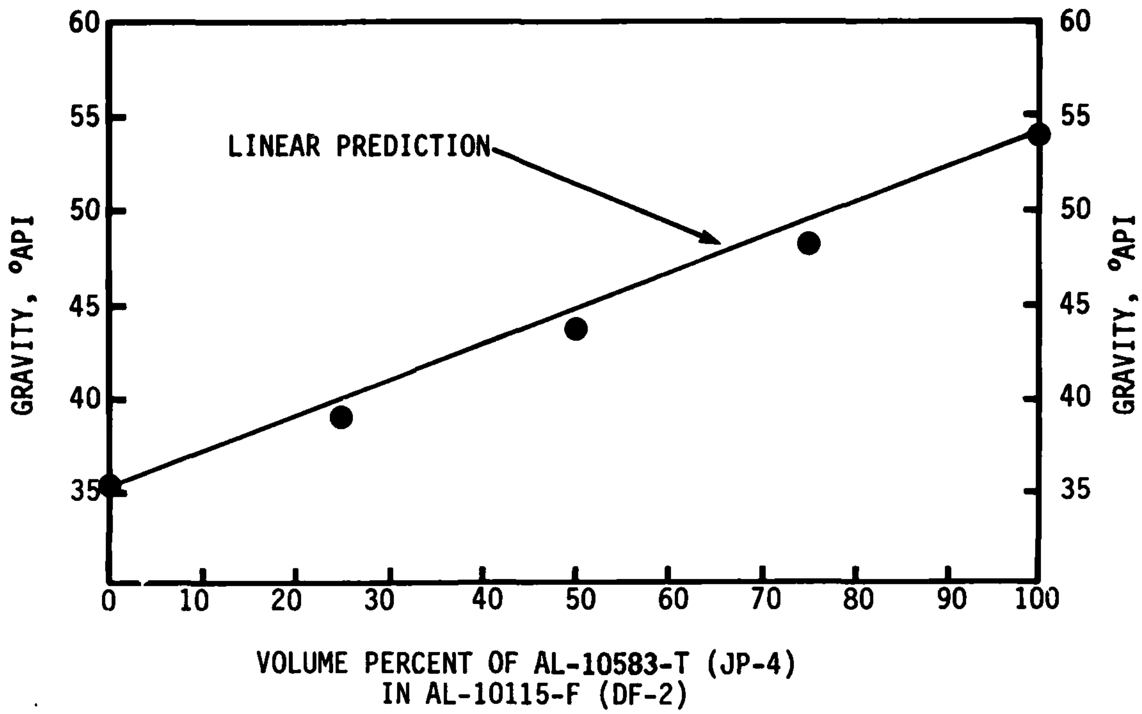


FIGURE 6. CETANE NUMBER BLENDING



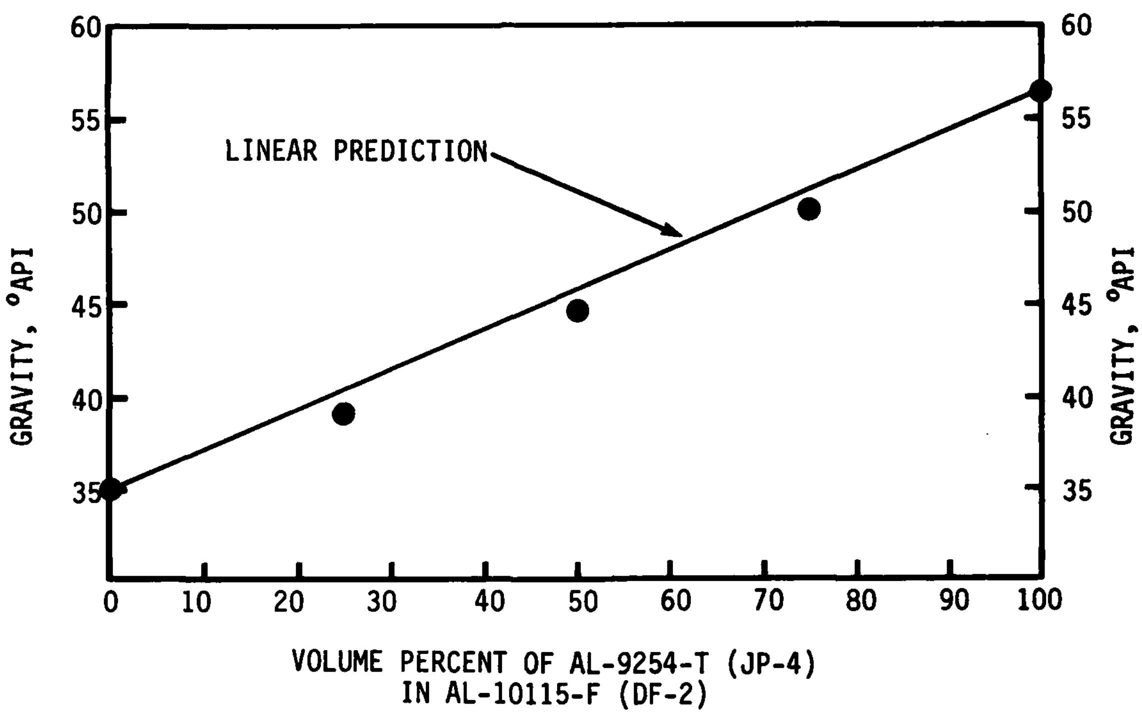
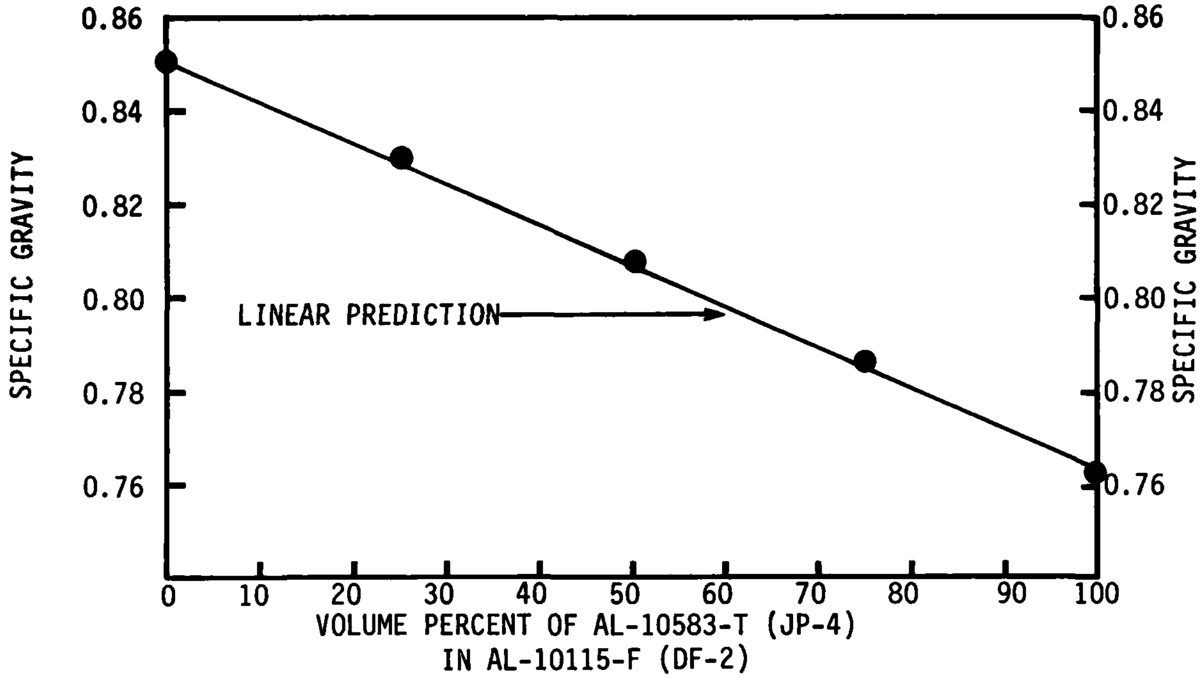


FIGURE 7. API GRAVITY BLENDING



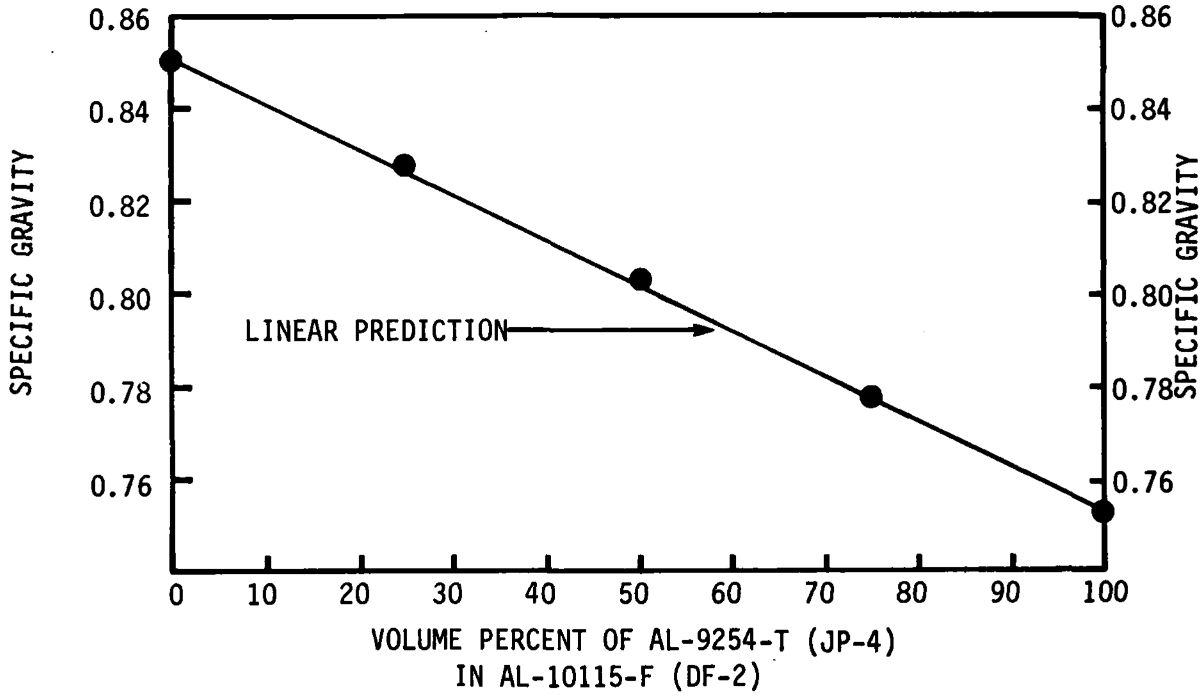


FIGURE 8. SPECIFIC GRAVITY BLENDING

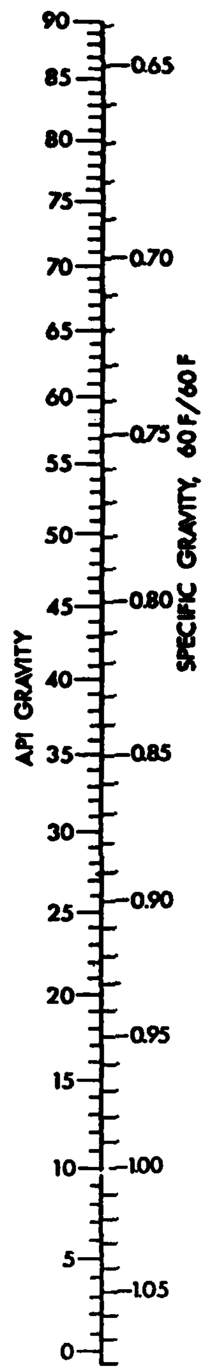


FIGURE 9. GRAPHICAL RELATIONSHIP BETWEEN API GRAVITY AND SPECIFIC GRAVITY

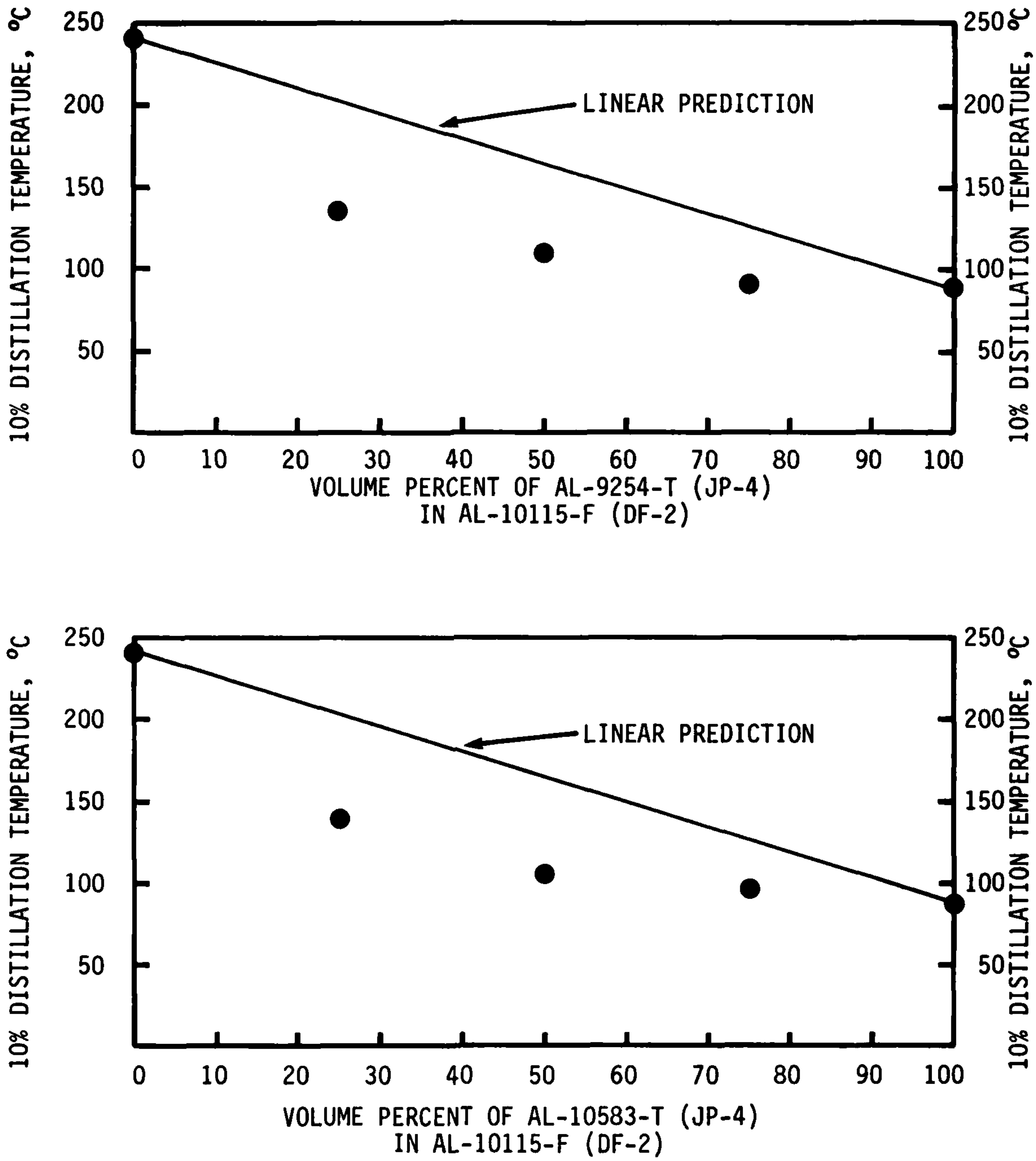


FIGURE 10. 10% DISTILLATION TEMPERATURE

If the entire distillation range is desired, the calculation can be more easily accomplished by plotting the distillation curves of the blending stocks and spacing the curve for the blend from the two blending stocks along the percentage axes that is inversely proportional to the amount of each blending agent. Unfortunately, this approach does not apply to blends of widely differing characteristics such as JP-4 and DF-2 or gasoline and JP-5. For these blends, the distillation temperature must be determined by measurement in the laboratory.

e. Kinematic Viscosity

The viscosity of a blend may be predicted using the viscosity-blending chart shown in Figure 11. This chart is based on the 0°-100°F portion of the temperature scale found in the ASTM Viscosity-Temperature chart, ASTM D 341 Chart V; however, the intervals on the abscissa, which on the ASTM chart become smaller as the temperature increases from 0° to 100°F, have been modified to be equal for blending estimates. The viscosity at constant temperature versus component percentage may be graphically illustrated for a binary blend. For convenience, the higher viscosity is marked at the 100 abscissa, the lower viscosity marked at the 0 abscissa, and a straight line drawn to connect these two points. The viscosity of any blend of these two components is read on this line at the point representing the volume percent of the high viscosity component. The data points on both charts of Figure 11 represent measured viscosities for the blends as indicated, and are very close to the predicted values. Other techniques for blending petroleum fractions to a given viscosity have been published and utilized successfully. (10)

3. Substitute Fuels

Most of the products suggested above as extenders for diesel fuels could also be used as substitute fuels. Table 9 lists the products that could be used as field emergency fuels and the specification requirements that pertain to compression ignition engine operation. Many of the properties identified as crucial for engine operation are not part of the specification for

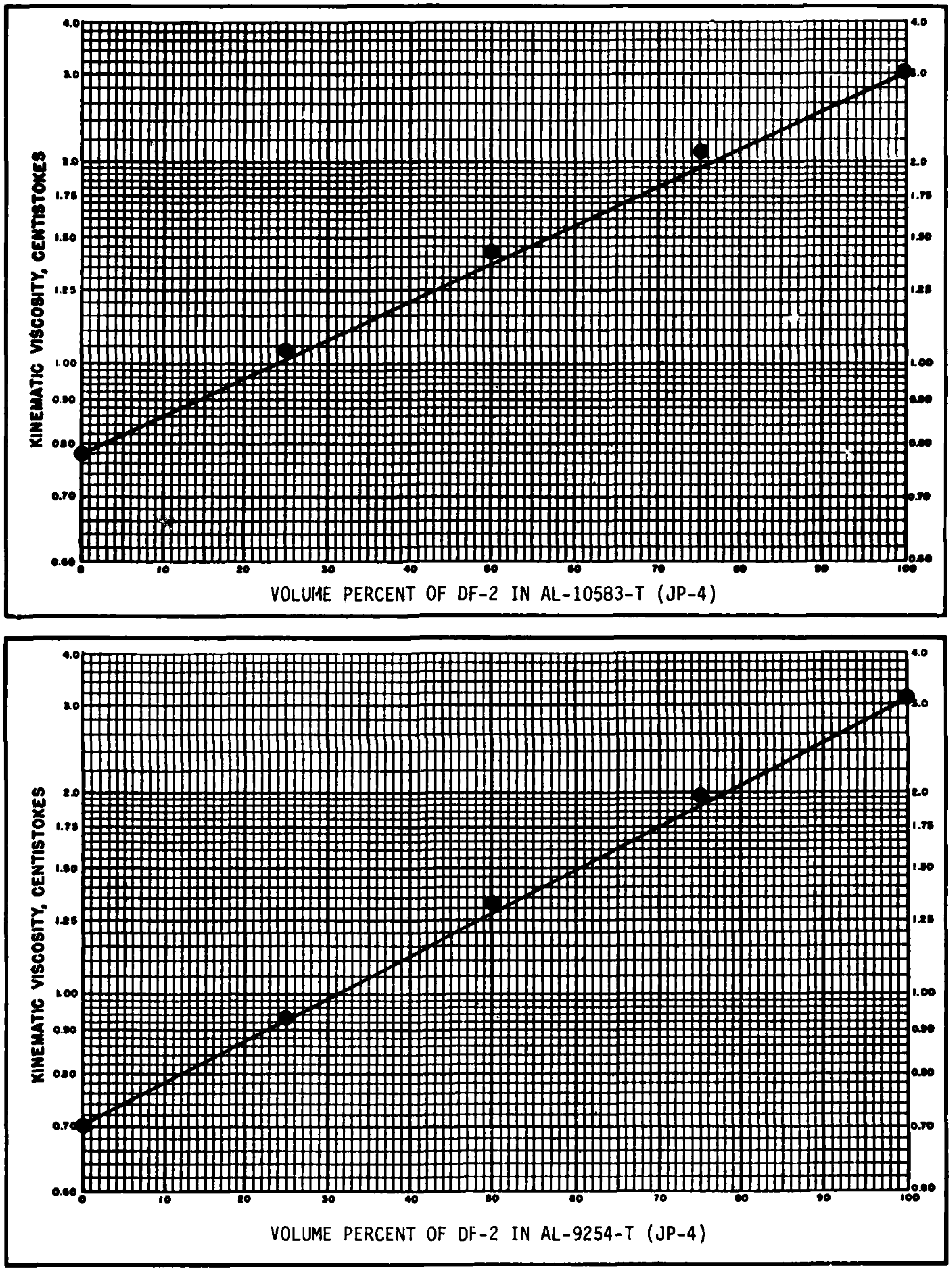


FIGURE 11. KINEMATIC VISCOSITY BLENDING

TABLE 9. EXISTING SPECIFICATION REQUIREMENTS OF POTENTIAL FIELD EMERGENCY FUELS FOR COMPRESSION-IGNITION ENGINES

	JP-4 MIL-T-5624	JP-8 MIL-T-83133	Jet A/A1 ASTM D 1655	Kerosene ASTM D 3699	No. 1 Fuel Oil VV-F-815	No. 2 Fuel Oil VV-F-815	No. 4 Fuel Oil VV-F-815	Dry Clean Solvent PD 680 Type II	Hydraulic Fluid MIL-H-5606
Gravity °API	45-57	NR*	NR	NR	35 min	30 min	30 max	NR	NR
Specific Gravity at 15/15°C	0.751-0.802	NR	NR	NR	0.8499 max	0.8762 max	0.8762 min	NR	NR
Distillation, °C									
10% recovered	NR	205 max	204.4 max	205 max	215 max	NR	NR	177 min	NR
20% recovered	145	NR	NR	NR	NR	NR	NR	NR	NR
50% recovered	190	NR	NR	NR	NR	NR	NR	NR	NR
90% recovered	270	NR	NR	NR	NR	NR	NR	NR	NR
EP	NR	300 max	300 max	300 max	NR	NR	NR	213 max	NR
Flashpoint, °C	NR	38 min	38 min	38 min	38 min	38 min	38 min	59 min	93 min
K Viscosity at 40°C, cSt	NR	NR	NR	1.0-1.9	NR	NR	NR	NR	NR
K Viscosity at 100°F, cSt	NR	NR	NR	NR	1.4-2.2	2.0-3.6	2.0-5.8	NR	1.40 min
Cetane number	NR	NR	NR	NR	NR	NR	NR	NR	NR
Sulfur, mass%	0.40 max	0.30 max	0.30 max	0.04/ 0.30+	0.5 max	1.0 max	NR	NR	NR
Cloud point, °C	NR	NR	NR	NR	NR***	NR***	NR	NR	NR
Freezing point, °C	-58 max	-50 max	-40/ -47** max	-30 max	NR	NR	NR	NR	NR
Aromatics, vol%	25 max	25 max	NR	NR	NR	NR	NR	NR	NR
Net heat of combustion, MJ/kg	42.8 min	42.8 min	NR	NR	report	report	report	NR	NR

*NR = No requirement.
**Jet A is -40°C max, Jet A-1 is -47°C max.
***There are no requirements for cloud point in No. 1 and No. 2 fuel oils; however, pour points are specified in Federal Specification VV-F-815D, and should be at or below the 10th percentile minimum ambient temperature as detailed in Appendix 1 of that specification.
+No. 1-K is 0.04 max, No. 2-K is 0.30 max.

these products. In Table 10, typical properties for the products listed in Table 9 are shown.

Cetane number is not a specification requirement for any of these products; however, the cetane index can be calculated by the ASTM D 976 method provided API gravity and 50 percent distillation temperature are known. Distillation ranges and/or viscosities are specified for most of the proposed field emergency fuels.

a. JP-4

Aviation turbine fuel JP-4 and the commercial counterpart Jet B would not be expected to perform well in a diesel engine because of the low cetane and high volatility of most naphtha-type jet fuels. The cetane numbers of eight samples of JP-4 obtained in a survey program conducted at AFLRL in 1979 were measured by ASTM Method D 613 and compared to the calculated cetane indices by D 976. The data presented in Table 11 show cetane numbers ranging from a high of 37 to a low of 27.9 for the JP-4 samples. The calculated cetane indices correlate reasonably well with measured cetane numbers for most of the samples; however, in several instances, there were large differences between the values. Therefore, the use of calculated cetane indices to estimate the cetane numbers of JP-4 and Jet B aviation fuels is not always reliable.

b. JP-5, JP-8, Jet A, and Jet A-1

JP-5 is listed in AR 703-1 as an alternative fuel for DF-2 as shown in Table 1; however, other kerosene-type turbine fuels are not listed. These fuels would be expected to perform adequately as substitute fuels in diesel engines. Cetane number and kinematic viscosity at 40°C are tests that are not required for JP-5 aircraft turbine fuel, or for other kerosene-type jet fuels; JP-8, and commercial Jet A and Jet A-1. In order to evaluate these and other properties considered to be important for compression-engine operation, requests were made for refiners to submit samples of their jet fuel products. Recently, the U.S. Navy instituted a policy by which DF-2

TABLE 10. TYPICAL PROPERTIES OF POTENTIAL FIELD EMERGENCY FUELS FOR COMPRESSION IGNITION ENGINES

	JP-4 MIL-T-5624	JP-8 MIL-T-83133	Jet A/A1 ASTM D 1655	Kerosene ASTM D 3699	No. 1 Fuel Oil VV-F-815	No. 2 Fuel Oil VV-F-815	No. 4 Fuel Oil VV-F-815	Dry Clean Solvent PD 680 Type II	Hydraulic Fluid MIL-H-5606
Gravity °API	53.9	47.9	42.5	-*	42.5	34.5	23.4	49.1	32.8
Specific Gravity at 15/15°C	0.7632	0.7887	0.8132	-	0.8132	0.8524	0.9135	0.7835	0.8612
Distillation, °C									
IBP	58	164	170	166	178	188	-	185	222
10% recovered	95	172	189	183	197	219	-	187	234
50% recovered	134	179	214	204	219	261	-	190	249
90% recovered	200	204	246	236	248	310	-	197	297
EP	247	260	275	254	271	339	-	208	306
Flashpoint, °C	-34	44	49	52	58	74	92	61	107
K Viscosity at 40°C, cSt	0.75	1.08	1.5	1.4	-	-	-	-	15.5
K Viscosity at 100°F, cSt	-	-	-	-	1.63	2.72	16.3	-	-
Cetane number	33	43	45	-	-	-	-	-	44
Sulfur, mass%	0.03	0.01	0.06	0.013 (No. 1K) 0.216 (No. 2K)	0.07	0.25	0.86	None	0.01
Cloud point, °C	-59	-55	-44	-	-25	3	-	-	-65
Pour point	-66	-65	-	-	-32	-15	-12	-	-65
Freezing point, °C	-62	-44	-45	-42	-	-	-	-	-
Aromatics, vol%	13.5	13	17.9	-	-	-	-	-	-
Olefins, vol%	0.8	1	1.1	-	-	-	-	-	-
Net heat of combustion, MJ/kg	43.480 min	43.43	43.193	-	-	-	-	41.860	-

*- = No data available.

TABLE 11. CETANE NUMBERS AND CETANE INDICES FOR JP-4 SAMPLES

AFLRL Code No.	Fuel	Cetane Number D 613	Cetane Index D 976
AL-7419-T	JP-4	35.1	31.9
AL-7429-T	JP-4	37.0	39.6
AL-7477-T	JP-4	31.8	28.7
AL-7485-T	JP-4	29.8	24.2
AL-7495-T	JP-4	35.4	41.4
AL-7498-T	JP-4	33.6	36.4
AL-7504-T	JP-4	27.9	10.6
AL-7580-T	JP-4	36.6	37.1
AL-7578-T	JP-4	ND	22.4

ND = Not determined

would no longer be supplied to the Marine Corps for operation of vehicles with compression ignition engines. Instead, JP-5 would be used in these engines. A request for samples was made by DFSC to those companies currently under contract to supply JP-5 for the U.S. Navy, and a second request for samples of kerosene-type jet fuel was made to petroleum companies, domestic and foreign, known to be supplying these types of fuel. These requests resulted in the receipt of 23 samples identified as JP-5, 35 samples of Jet A, and 9 identified as Jet A-1. The Jet A-1 fuel is not manufactured in the continental United States, therefore, all of these samples were from foreign refineries. No JP-8 samples were received; however, the properties of JP-8 and Jet A-1 are virtually identical with the exception that JP-8 requires the presence of a fuel system icing inhibitor and a corrosion inhibitor. The properties of interest for all these samples were measured at AFLRL when the data were not supplied by the refiner, and are tabulated in Appendix A, Tables A-1, A-2, and A-3. The range of values and averages obtained for properties of interest to compression-ignition engine operation have been

summarized in Tables 12, 13, and 14 for the JP-5, Jet A, and Jet A-1 fuels, respectively. The data for the JP-5 fuels in Table 12 indicate that all these fuels are within a narrow range of properties. Four samples had cetane numbers below 40, the minimum value for DF-1; however, even the JP-5 with 34.8 cetane number would be expected to operate in most compression ignition engines. One of the Jet A samples had a measured cetane number below 40, and two of the Jet A-1 samples had cetane numbers below 40. The cetane indices for the JP-5, Jet A, and Jet A-1 samples were relatively close to the measured cetane numbers.

The data in Tables 12, 13, and 14 indicate that the three types of fuels have very similar properties, the principal differences being in the vola-

TABLE 12. AVERAGES AND RANGE OF VALUES FOR PROPERTIES OF 23 JP-5 SAMPLES

	Average	High	Low	DF-2 Requirements CONUS	OCONUS
Gravity, °API	40.7	44.1	36.3	NR*	NR
Density at 15°C, kg/L	0.8213	0.8428	0.8054	NR	0.815-0.860**
Flash point, °C	65	73	65	52 min	56 min
Viscosity at 40°C, cSt	1.5	1.7	1.3	1.9 to 4.1	
at 20°C, cSt					1.8 to 9.5
Cetane number	42.0	47.5	34.8	45 min**	45
Cetane index	41.7	47.2	36.5	NR	NR
Distillation, D 86, °C					
10% Recovered	196	204	188	NR	NR
50% Recovered	214	223	204	Report	Report
90% Recovered	241	267	226	338 max	357 max
Aromatics, FIA, vol%	20.8	25.0	15.0	NR	NR
Cloud point, °C	-	-45	§-60	+	-13
Freezing point, °C	-	-46	-74	NR	NR
Hydrogen, mass%	13.59	13.84	13.34	NR	NR
Net heat of combustion, MJ/L	35.40	36.10	34.71	36.43++	NR

*NR = No requirement.
**40 min cetane number is currently accepted for DF-2.
+At or below anticipated ambient temperature at location of use. (See Appendix A of VV-F-800C for guidance.)
++Typical value for a reference diesel fuel.

TABLE 13. AVERAGES AND RANGE OF VALUES FOR PROPERTIES OF 35 JET A SAMPLES

	Average	High	Low	DF-2 Requirements CONUS	DF-2 Requirements OCONUS
Gravity, °API	42.9	48.4	37.9	NR*	NR
Density at 15°C, kg/L	0.8110	0.8349	0.7862	NR	0.815-0.860**
Flash point, °C	55	68	43	52 min	56 min
Viscosity at 40°C, cSt	1.5	1.7	1.1	1.9 to 4.1	
at 20°C, cSt					1.8 to 9.5
Cetane number	45.2	51.9	36.3	45 min**	45 min
Cetane index	44.2	49.5	35.8	NR	NR
Distillation, D 86,°C					
10% Recovered	189	200	172	NR	NR
50% Recovered	211	226	193	Report	Report
90% Recovered	242	259	199	338 max	357 max
Aromatics, FIA, Vol%	18.5	21.9	12.0	NR	NR
Cloud point, °C	-	-35	<-60	+	-13
Freezing point, °C	-	-42	-59	NR	NR
Hydrogen, mass%	13.82	14.82	13.36	NR	NR
Net heat of combustion					
MJ/L	35.04	35.85	34.12	36.43++	NR

*NR = No requirement.
**40 min cetane number is currently accepted for DF-2.
+At or below anticipated ambient temperature at location of use. (See Appendix A of VV-F-800C for guidance.)
++Typical value for a reference diesel fuel.

TABLE 14. AVERAGES AND RANGE OF VALUES
FOR PROPERTIES OF 9 JET A-1 SAMPLES

	Averages	High	Low	DF-2 Requirement CONUS	DF-2 Requirement OCONUS
Gravity, °API	44.9	49.3	41.3	NR*	NR
Density at 15°C, kg/L	0.8018	0.8185	0.7823	NR	0.815-0.860**
Flash point, °C	43	51	36	52 min	56 min
Viscosity at 40°C, cSt	1.3	1.4	1.0	1.9 to 4.1	
at 20°C, cSt					1.8 to 9.5
Cetane number	42.6	48.1	34.7	45 min**	45
Cetane index	43.4	47.0	38.2	NR	NR
Distillation, D 86, °C					
10% Recovered	174	183	166	NR	NR
50% Recovered	199	213	181	Report	Report
90% Recovered	233	242	202	338 max	357 max
Aromatics, FIA, Vol%	19.4	21.0	18.1	NR	NR
Cloud point, °C	-	-45	-60	+	-13
Freezing point, °C	-	-49	-61	NR	NR
Hydrogen, mass%	13.84	14.12	13.62	NR	NR
Net heat of combustion, MJ/L	34.65	35.20	33.92	36.43++	NR

*NR = No requirement.
**40 min cetane number is currently accepted for DF-2.
+At or below anticipated ambient temperature at location of use. (See Appendix A of VV-F-800C for guidance.)
++Typical value for a reference diesel fuel.

tility as reflected by flash points and distillation temperatures and in freezing points. The JP-5 has the highest flash point temperatures, followed by Jet A and then Jet A-1. The distillations follow in the same order. Jet A-1 samples generally have the lowest freezing point temperatures, and the JP-5 samples are in the same range. The Jet A fuels have the highest freezing points.

In summary, the data indicate that kerosene-type jet fuels (JP-8, Jet A, and Jet A-1) can be utilized as field emergency fuels for compression ignition engines with only minor performance debits, due to lower net heat of combustion values compared to nominal DF-2. As noted earlier, JP-5 is designated as an alternate fuel. A minimum of performance reduction would occur with these products.

c. Kerosene

Kerosene meeting the specifications for ASTM D 3699 would probably have much of the same properties as aircraft turbine fuels JP-5, JP-8, Jet A, and Jet A-1. This similarity is apparent when the distillation ranges in Table 9 are compared. The viscosity range for this kerosene is similar to the range of measured values observed for the jet fuels. It appears that commercial kerosene would perform adequately as a field emergency fuel for compression ignition engines.

d. VV-F-815 Nos. 1, 2, and 4 Fuel Oil

Numbers 1 and 2 fuel oil have the same boiling ranges and viscosity requirements as DF-1 and DF-2. The fuel oils have no cetane number requirement and can contain more sulfur than the diesel fuels. Nevertheless, Numbers 1 and 2 fuel oils should perform adequately as field emergency fuels. Number 4 (light) fuel oil has a slightly higher viscosity range, but still would be expected to perform adequately as a field emergency fuel.

e. Dry Cleaning Solvent, PD 680, Type II

The PD 680, Type II, dry cleaning solvent is a hydrocarbon solvent with a boiling range similar to kerosene. Based on the specification requirements, it is believed that this product would perform adequately as a field emergency fuel. A sample of solvent specifically designated PD 680, Type II, was not obtained for laboratory evaluation; however, a Stoddard solvent meeting the requirements of this specification was evaluated.

f. Fog Oil, MIL-F-12070

The specification for Fog Oil, MIL-F-12070A, shows two types: Type SGF1 and Type SGF2. It was not possible to obtain samples of either type for evaluation; however, the specification viscosity requirements indicate that Type SGF2 is a light lubricating oil base stock known as 100 vis neutral and Type SGF1 is even more viscous. The boiling range for Type SGF1 is determined by vacuum distillation at 10 mm Hg. Due to the high viscosity of these fog oils, they would probably not be suitable as substitute/emergency fuels; however, they would be expected to perform adequately blended with kerosene, jet, or diesel fuel. Maximum concentrations of fog oils blended with other fuels have not been established.

g. Hydraulic Fluid, MIL-H-5606D

Samples of petroleum-base hydraulic fluids meeting requirements of MIL-H-5606D and MIL-H-6083D were obtained and evaluated for properties that would pertain to utilization of those materials as emergency fuels in a diesel engine. The data are shown in Table 15 and indicate that these fluids have adequate cetane numbers for diesel engine operation; however, the viscosity at 40°C is too high for satisfactory operation. Dilution with DF-2 or DF-1 would reduce the viscosity to a satisfactory range. A blend of 40 percent of the MIL-H-5606D fluid in DF-2 with a viscosity of 3.2 cSt at 40°C would have a viscosity of about 5.5 cSt at 40°C. The MIL-H-6083D is a corrosion-preventive oil and thus contains a organometallic additive which produces the high ash value, 0.7 wt%, shown in Table 12. Therefore, it may not be desirable to use MIL-H-6083D hydraulic fluids as emergency fuel extenders for long periods, since the high ash value could be damaging to the engines.

h. Gasolines

Gasolines identified as MIL-G-3056 (MOGAS), F-46, F-49, and F-59 are not suitable as emergency fuels for compression-ignition engines. It is doubtful that these engines would ever start on gasolines; therefore, it is recommended that no gasolines be listed as emergency or substitute fuels for

TABLE 15. PROPERTIES OF HYDRAULIC FLUIDS

Property	AL-10737-L MIL-H-5606D Hydraulic Fluid	AL-5074-L MIL-H-6083D Hydraulic Fluid
Gravity, °API	32.8	32.9
Viscosity at 40°C, cSt	15.5	12.58
Flash Point, °C	107	103
Cloud Point, °C	-65	-60
Pour Point, °C	-65	-63
Distillation, °C, D 86		
10%	234	232
20%	238	238
50%	249	259
90%	297	333
Residue, %	1.0	1.0
Loss	0	0
Cetane Number	44	44
Sulfur, Total, wt%	0.01	0.19
Ash, %	0	0.7
Net Heat of Combustion,		
Btu/lb	17,997	---
MJ/kg	41.860	---

diesel fuels. Table 1 of this report does not show gasoline as emergency fuels for compression-ignition engines.

C. FEF for Diesel-Consuming Multifuel Engines

The four-cycle MAN combustion system family of multifuel engines, designated the LD-465, LDT-465, and LDS-465, can be operated on a wide range of fuels. Table 1 shows a range from gasoline to NATO F-75 Navy distillate as alternate fuels for this engine.

1. Limiting Fuel Properties for Emergency Engine Operation

It is anticipated that the limiting properties for a field emergency fuel to operate the multifuel engine would encompass the properties of gasoline as well as those of Navy distillate fuel; therefore, the properties of diesel, distillate burner fuel, jet fuels, and gasohol would be encompassed into

these limits. Recent work conducted at AFLRL indicated that the LDT-465-1C engine would not operate on gasohol with a cetane number of 13 at 40°F, but would operate on a gasohol with a cetane number of 16 at 52°F. (11) This would seem to indicate that the multifuel engine is limited by a minimum cetane number of about 15. Earlier work at AFLRL showed that many gasolines identified as regular grade, with antiknock index (R+M)/2 of about 89, have cetane numbers in the range of 12 to 16, and premium grade gasolines (R+M)/2 of 91 and above have cetane number of 7 to 9. (12) Based on these observations, AVGAS and premium grade automotive gasolines should not be considered as emergency fuels for the multifuel engines.

2. Extenders for Diesel Fuel in Multifuel Engines

Those materials listed as extenders for diesel fuel to be used in compression-ignition engines should be satisfactory for use with the multifuel engines also. These are: JP-5, JP-8, VV-F-815 Nos. 1, 2 and 4 fuel oils; PD-680 Types I and II dry cleaning solvent; commercial kerosene; MIL-F-12070A, Fog Oil; and MIL-H-5606 Hydraulic Fluid. Blending of naphtha-type materials such as JP-4 and P-D 680 Type I dry cleaning solvent with diesel fuel should be performed with extreme caution due to the attendant flammability hazards created. Gasolines and gasohol can be added to this list, but blending should be carried out with extreme caution. The blending of diesel fuel with gasohol can also result in phase separation of the gasohol, producing a layer of ethanol in the bottom of the fuel tank. Therefore, this combination is not recommended.

3. Substitute Fuels

All the materials listed in the preceding paragraph with the exception of fog oil and hydraulic fluid, should be adequate substitute fuels for diesel in multifuel engines. Gasoline, a fuel listed as alternate fuel for this engine in AR 703-1, may not be adequate if it is a premium grade or regular grade with a high octane number. Therefore, if gasoline is to be used as a field emergency fuel, blending with up to 10 percent diesel fuel is recommended to ensure raising of the cetane number of the blend to within tolerance limits of the multifuel engine.

Certain combustible materials existing in the military system that may be thought of as possible substitutes or emergency fuels in the multifuel engine may not be adequate due to the limitation of 15 cetane number for fuels in this engine. Materials such as AVGAS, premium gasoline, methanol and ethanol generally have cetane numbers too low for starting and running in multifuel engines.

D. FEF for Ground Turbine Engines

Operation of the simple-cycle, gas-turbine engine is based on the Brayton or Joule cycle, which consists of adiabatic compression, constant pressure heating, and adiabatic expansion. Compressed air is directed toward the combustion chamber where it is mixed with vaporized fuel to support the combustion. Excess air passes around the flame, cooling metal surfaces, and combining with those gases which are rapidly expanding from combustion. The resulting gas stream is expanded through one or more turbine wheels which drive the compressor and provide the output power. In a simple-cycle gas turbine, the gas is exhausted; in a regenerative-cycle engine, the exhaust gas is directed through a heat exchanger to heat the combustor inlet air.

A wide range of gas-turbine engines is in use from large industrial gas turbines for electrical generation to smaller ones for aircraft and ground vehicles. Selection of the fuel for use in these engines requires consideration of the availability of the fuel, design of the gas turbine, and fuel-handling systems and maintenance/operating requirements.

In addition to numerous helicopters, the U.S. Army combat fleet includes the M-1 tank powered by a gas turbine engine. The AGT-1500 engine in the M-1 battle tank was designed to use DF-2 as the primary fuel since this fuel is also the primary fuel for most other tactical/combat ground vehicles, as well as turbine/CI-powered electrical generators.

1. Limiting Fuel Properties for Emergency Engine Operation

References to research work or manufacturers recommendations for limiting

fuel properties that would permit emergency operation of the gas turbine engine were not found in the literature. Since AR 703-1 lists MOGAS and AVGAS (Table 1) as emergency fuels for ground equipment gas turbines, it appears that the limiting fuel properties are quite broad.

2. Extenders for Gas Turbine Engines Fuels

Although the M-1 tank engine was designed for burning DF-2, it is a tolerant engine with respect to fuel. The list of alternative fuels in AR 703-1, shown in Table 1, is extensive and includes all aircraft turbine fuels in military and ASTM specifications. Numbers 1 and 2 burner fuels are included, but not number 4. Based on these observations, it would appear that all fuels and combustible materials listed as fuel extenders for diesel engines would also apply to ground turbine engines, with the exception of number 4 burner fuels and hydraulic oils. Further investigations are needed to determine the fuel viscosity and boiling range limitations for the ground gas turbine engines, although the manufacturer of the AGT-1500 gas turbine engine has indicated that a maximum of 12 cSt is the limiting fuel viscosity for start-up of this engine.

3. Substitute Fuels

The range of combustible liquids that could be used as substitute fuels for the ground gas turbines has not been determined; however, it appears that most of the materials listed for the multifuel, compression ignition engine would also be suitable for these engines with a few exceptions. These engines may be limited to operation with fuels of certain viscosity and boiling range. Therefore, they may not operate with materials such as number 4 burner fuels, hydraulic fluid, and even perhaps Navy distillate. Methanol, ethanol, and other alcohols and oxygenated products, on the other hand, may be adequate field emergency fuels. This area needs further investigation.

E. FEF for Aircraft Engines

Field emergency fuels for aircraft engines, both spark-ignited and gas

turbine, should be limited to those fuels listed as alternate in AR 703-1. For spark-ignition engines, these are:

MIL-G-5572 (AVGAS), Grade 115/145,
F-22; and ASTM D 910 (AVGAS)

MIL-T-5624, grade JP-4, NATO F-40, is the primary fuel for gas turbine aircraft, and the only alternate fuels shown are JP-8, JP-5, and ASTM D 1655 (commercial aviation fuels).

Determination of the existence of field emergency fuels as extenders or substitutes for aircraft equipment should be made only after extensive investigation.

III. CRUCIAL FUEL PROPERTIES AND BLENDING CORRELATIONS

The properties of fuels measured in the laboratory are for the most part related to their performance in an engine. A few fuel properties are considered to be crucial for each type of engine. For example, engines designed to burn gasoline will not run at all on a number 6 burner fuel because the volatility needed for producing the required air-fuel mixture in the carburetor is nonexistent in this heavy fuel.

The crucial properties required of fuels, even for emergency operation of the various engine types in the system, are listed in order of importance below:

For spark ignition engines: Vapor pressure, distillation, and octane number;

For compression-ignition two- and four-cycle engines: Cetane number, viscosity, distillation, and cloud points (in cold weather operation, cloud point becomes the most important property);

For multi-fuel engines: Viscosity and cetane number.

The fuel properties crucial to turbine engine emergency operation are de-

pendant on the design of the engine to a large extent, and to ambient conditions. An engine designed to operate on DF-2 such as the AGT-1500 gas turbine used in the M-1 tank may not operate long on a low viscosity material such as methanol or on a high viscosity residual fuel. Therefore, viscosity appears to be a crucial property, although this engine can operate on gasoline, turbine, and diesel fuels with a wide range of viscosities. The manufacturer has indicated that start-up of the AGT-1500 engine is limited to fuels with viscosities below 12 cSt at operating temperatures. For cold weather operation, cloud point is very critical, since a fuel with high cloud point will exhibit separation of wax at temperatures below its cloud point, causing blockage of fuel lines and filters.

A. Spark-Ignition Engine Fuels

1. Estimation of Distillation Characteristics of Fuel Blends

As stated earlier, when blending similar materials with known boiling characteristics, the distillations curve of the blend can be calculated. When blending products of widely different boiling ranges, these calculations cannot be made. Table 16 shows the distillation temperatures for a gasoline, JP-5, and two blends of these fuels. Calculations of temperatures at the initial boiling point, 10 percent, 20 percent, 50 percent, 70 percent, 90 percent, and end point for the 50/50 and 75/25 blends were made, and as can be observed in Table 16, failed to agree with measured values. If the distillation characteristics of blends of widely different boiling range fuels are needed, the best approach is to determine the distillation range in the laboratory.

2. Estimation of Reid Vapor Pressures of Fuel Blends

The Reid vapor pressure method is a technique used to measure the volatility of gasolines. This property is important for obtaining the correct air-fuel mixture in a spark-ignition engine for satisfactory operation. Too low a Reid vapor pressure for the fuel being used will not permit the engine to start and too high a vapor pressure will cause premature vaporization in the

TABLE 16. DISTILLATION DATA FOR BLENDS OF JP-5 AND GASOLINE

Distillation, °C	AL-10937-G Gasoline	AL-7247-T JP-5	50/50 Blend Calculated	50/50 Blend Measured	75/25 Blend Calculated	75/25 Blend Measured
IBP	28	179	103	34	66	28
5% Recovered	50	193	-	63	-	49
10% Recovered	61	199	130	89	96	68
15% Recovered	72	203	-	103	-	85
20% Recovered	82	205	144	113	113	95
30% Recovered	97	208	-	130	-	108
40% Recovered	104	213	-	148	-	117
50% Recovered	110	218	-	177	-	127
60% Recovered	114	224	-	198	-	141
70% Recovered	121	229	175	210	148	171
80% Recovered	133	238	-	222	-	199
90% Recovered	159	246	202	236	181	223
95% Recovered	176	252	-	246	-	238
EP	213	266	240	259	226	254
% Recovered	99.5	99	-	98.5	-	99
% Residue	0.5	1	-	1.5	-	1
% Loss	0	0	-	0	-	0

fueling system, resulting in vapor lock. During the manufacturing of gasolines, the refiners often blend three, four or more blending stocks to produce the final product. In order to predict the properties of the final blend, charts of blending indices have been developed. One such empirical method for estimating Reid vapor pressures of blends was developed by Chevron Research Company and has been published as a table containing values called vapor pressure blending indices (VPBI).(13) This table is reproduced in Appendix B (Table B-1). The VPBI values were used to estimate the Reid vapor pressures of the blends of gasoline with JP-4, JP-5, and DF-2 shown in Table 17 and compared to the measured values. The calculation and compar-

TABLE 17. MEASURED AND CALCULATED REID VAPOR PRESSURES

Component	Volume Fraction	Vapor Pressure, psi	Vapor Pressure Blending Index	Volume Fraction x VPBI	Calculated RVP	Measured RVP
Gasoline	0.75	8.9	15.4	11.55		
JP-4	0.25	2.9	3.78	0.94		
				12.49	7.5	6.9
Gasoline	0.5	8.9	15.4	7.7		
JP-4	0.5	2.9	3.78	1.89		
				9.59	6.1	5.6
Gasoline	0.75	8.9	15.4	11.55		
JP-4	0.25	2.1	2.52	0.63		
				12.18	7.4	7.1
Gasoline	0.5	8.9	15.4	7.7		
JP-4	0.5	2.1	2.52	1.26		
				8.96	5.8	5.7
Gasoline	0.75	8.9	15.4	11.55		
Jet A	0.25	0	0	0		
				11.55	7.1	6.8
Gasoline	0.50	8.9	15.4	7.7		
Jet A	0.50	0	0	0		
				7.7	5.1	5.1
Gasoline	0.75	8.9	15.4	11.55		
DF-2	0.25	0	0	0		
				11.55	7.1	7.3

*Based on Reid Vapor Pressure Blending Index Numbers (13)

ison are shown in Table 17. The calculated RVP's utilizing the VPBI's appear to agree more closely with measured values than the estimation of these values based on linear blending as shown in Figure 5.

3. Estimation of Octane Numbers of Fuel Blends

Refiners, when producing gasoline with a given octane number, mix their

blending stocks proportionally according to the "blending octane number" of each component. Experience has shown that when two materials are mixed, the high-octane material usually behaves as if it has higher octane number than obtained by laboratory engine tests of the materials. This higher octane number is referred to as the blending octane number and is based on experience.(14) The blending octane of the high-octane or blending agent is defined as CN_a in which C is a factor for each particular pair of components, and N_a is the octane number (Motor or Research) of the high-octane blending agent. The blending octane number is then used in an additive-type equation:

$$N = \frac{P_a\ (CN_a) + P_b\ (N_b)}{100}$$

where:

N = Octane number of the blend
P_a = Volumetric percentage of high octane blending agent
P_b = Volumetric percentage of base stock
N_a = Octane number of blending agent
N_b = Octane number of base stock
C = A factor for each pair of components

The value of the multiplier C can vary considerably because of the inherent differences in gasolines. Figure 12, reproduced from Nelson's Petroleum Refining Engineering (14), is an approximation for obtaining blending octane numbers of high octane components.

The application of octane blending numbers to blends of gasoline and other fuels, such as JP-4, JP-5, Jet A and DF-2, is not practical, since, as described above, these numbers are derived from experience. However, the linear or additive blending displayed graphically in Figures 1, 2, 3, and 4 provides approximations for octane numbers which should be adequate in application to field emergency fuel blending.

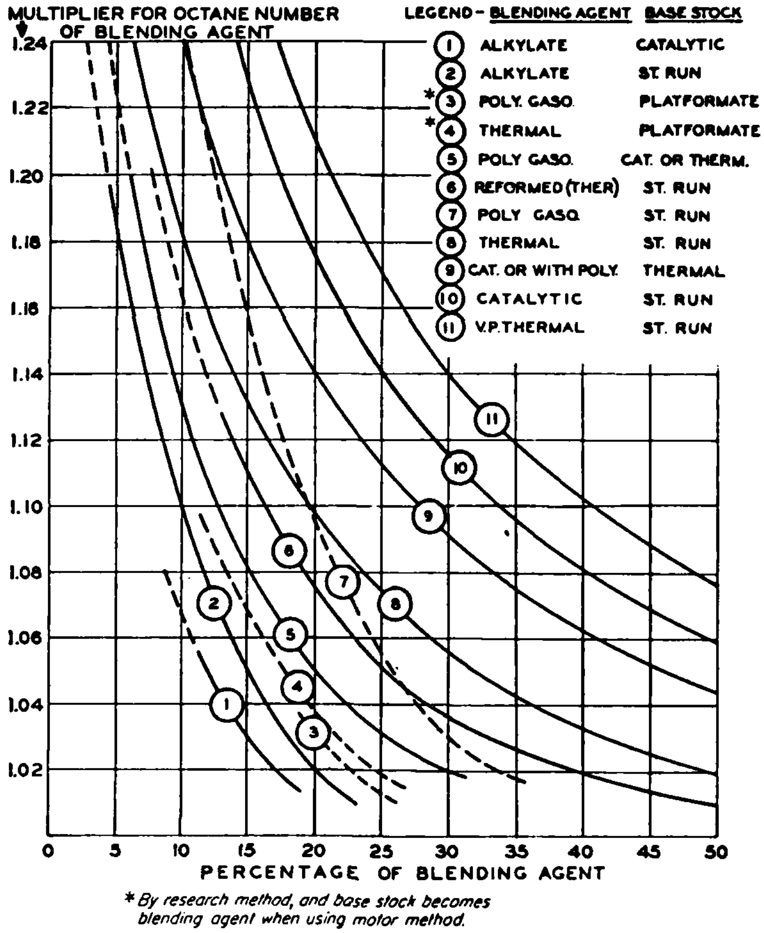


FIGURE 12. APPROXIMATION FOR OBTAINING THE BLENDING OCTANE NUMBERS OF HIGH-OCTANE COMPONENTS

B. Compression Ignition Engine Fuels

1. Estimation of Distillation Characteristics of Fuel Blends

Distillation properties of blended emergency fuels to be used in compression-engine fuels can be estimated in the same way as described for the spark-ignition engine fuels. Since the components of the blend presumably would differ widely in distillation characteristics, the predicted values for the blend will not be very close to determined data; nevertheless, a rough approximation of the expected values can be obtained.

2. Estimation of Cetane Numbers

The cetane number of a blended fuel can be estimated by the proportional addition of the cetane numbers of the components as shown in Figure 6 of this report.

3. Viscosities of Blended Fuels

The viscosities of blended fuels for compression ignition engines can be predicted by using a blending chart, as shown in Figure 11, or using viscosity blending indices.(10) A table of viscosity blending indices is reproduced in Appendix B.

4. Cloud Point of Blended Fuels

The cloud point of blended fuels is critical at low ambient temperatures; however, a cloud point blending correlation was not found. The method for estimating pour points of blends reported by Reid and Allen (15) may be useful for cloud points as well, but has not been evaluated. The pour point blending chart is reproduced in Appendix B.

C. Gas Turbine Engine Fuels (Ground Equipment)

No emergency fuel blends have been suggested for gas turbine engines; however, the blends suggested for compression-ignition engines should apply to gas turbines as well, and the properties of the blends can be estimated in the same manner.

IV. CONCLUSIONS AND RECOMMENDATIONS

Field emergency fuels as substitute fuels or as extenders for primary or alternate fuels have been tentatively identified for spark-ignition, compression-ignition, and gas turbine engines utilized in ground vehicles.

Spark-ignition engines that have as the primary fuel gasoline meeting MIL-G-3056 requirements (OCONUS) and VV-G-1690 requirements (CONUS), can be operated on the alternate fuels listed in Table 1. In an emergency, blends of the primary or alternate fuels with gasohol, JP-4, JP-8, JP-5, commercial jet fuels, DFA, DF-1, DF-2, and commercial diesel fuels, P-D 680 Type I dry cleaning solvent, FO-1, FO-2, and commercial No. 1 and No. 2 burner fuels may be considered. These fuel extenders are listed in their order of preference. Additional work is needed to define the operational characteristics of the blends and their long-term endurance effects prior to authorizing their use.

Compression-ignition engines that use VV-F-800, DF-2, as the primary fuel and JP-5 and commercial diesel fuels as alternate fuels, as shown in Table 1, can operate in an emergency on kerosene, JP-8, commercial jet fuels, DFM, gas turbine fuels, FO-1, FO-2, commercial burner fuels, 4-D diesel fuel, and Navy distillate. The order listed is presumed to be the ranking according to anticipated performance in the compression-ignition engines.

Analyses of numerous samples of kerosene-type jet fuels showed that 4 of 23 JP-5 samples had cetane numbers below 40, the lowest value being 34.8; three of the 44 Jet A/A-1 samples had cetane numbers below 40, the lowest value being 34.7. JP-5 is, however, an alternate fuel for compression ignition engines.

Field emergency fuels and fuel extenders for gas turbine engines in ground equipment are essentially the same as those listed for compression-ignition engines, augmented by military automotive and aviation gasolines. The equivalent commercial gasolines should also be suitable.

Crucial or critical fuel properties for operating the spark-ignition engines have been identified in order of importance as vapor pressure, distillation, and octane number. Correlations for estimating those properties in blended fuels are presented.

The crucial fuel properties for compression-ignition engine operation in order of importance are cetane number, viscosity, distillation, and cloud point. Estimation of all of these properties for blended fuels is possible through available correlations.

No crucial fuel properties or limits were identified for gas turbine engines in ground equipment except cloud point during cold weather operation. It was learned that the manufacturer of the AGT-1500 engine used in the M-1 tank has stated that a viscosity below 12 cSt is necessary for start-up of this engine.

Further work is needed to identify fuel property limits for gas turbine engine operation in ground equipment and those for aircraft engines, both spark-ignition and gas turbines.

The correlation available for calculating cetane index of fuels from their mid-point distillation temperature and API gravity (ASTM D 976) gives an approximation of the cetane index when applied to kerosene-type aircraft turbine fuels. Additional work should be conducted to apply better correlations to these fuels so that more accurate cetane indices can be calculated.

This report identifies numerous hydrocarbon liquids that could be used as field emergency fuels, either neat or blended with primary fuels, for use in ground vehicles. Additional followup work is needed to more fully define the limiting/crucial properties, conduct engine testing on prototype blends, and determine long-term effects of operating on these field emergency fuels, both in terms of combustion and engine lubrication.

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APPENDIX A

PROPERTIES OF AIRCRAFT TURBINE FUELS

TABLE A-1. PROPERTIES OF JP-5 SAMPLES

Sample Code	AL-10780-T	AL-10794-T	AL-10786-T	AL-10865-T	AL-10869-T	AL-10866-T	AL-10878-T	AL-10900-T	AL-10972-T
Property:									
Gravity, °API	41.8*	43.3*	38.9	43.2*	41.9	41.1*	42.3*	40.3*	36.8
Density									
@ 15°C, kg/L	0.8161	0.8091	0.8300	0.8096	0.8156	0.8194	0.8138	0.8232	0.8408
Cloud point, °C	-47	-49	-52	-60	-49	-49	-45	-46	-60
Freezing point, °C	-50*	-48*	-48*	-58*	-	-49*	-46*	-47*	-74*
Flash point, °C	70*	63*	69*	66*	62	68*	64*	66*	73*
Viscosity									
@ 40°C, cSt	1.5	1.6	1.7	1.4	1.7	1.5	1.4	1.6	1.7
Aniline point, °C (°F)	64.0 (147.2)	61.4 (142.5)	57.2 (135.0)	57.7 (135.9)	64.6 (148.3)	57.3 (135.1)	58.3 (137.0)	57.0 (134.6)	54.4 (130.0)
Cetane Number,									
D 613	46.3	45.4	40.8	43.1	47.4	43.6	44.7	43.4	34.8
Cetane Index,									
D 976-80	47.2	45.6	39.5	42.1	47.0	40.7	43.7	41.9	37.7
Sulfur, Mass%	0.04*	0.01	< 0.01	0.02*	< 0.01	0.01*	0.06*	0.04*	0.03*
Distillation,									
D 86 (D 2887) °C									
IBP	187 (134)	186* (139)	183 (167)	179* (140)	179 (145)	188* (136)	178* (136)	191* (147)	191* (140)
10% recovered	201 (186)	196 (172)	202 (197)	188 (173)	198 (177)	197 (186)	194 (171)	197 (175)	196 (179)
20% recovered	207 (197)	200 (187)	206 (209)	193 (185)	203 (191)	201 (196)	197 (184)	201 (190)	211 (194)
50% recovered	219 (223)	212 (214)	218 (238)	204 (209)	223 (227)	210 (216)	212 (213)	217 (218)	222 (223)
90% recovered	245 (261)	241 (253)	243 (272)	229 (244)	267 (283)	228 (245)	243 (255)	244 (263)	250 (262)
FBP	268 (293)	260 (293)	271 (295)	241 (273)	287 (321)	237 (264)	260 (294)	270 (306)	267 (297)
Residue, vol%	1.0	1.0	0.5	1.0	1.0	1.0	0.5	1.0	1.0
Loss, vol%	0	0	0.5	0	0	0	0	0	0
Aromatics, FIA, vol%	15.0	18.4	21.3	19.2	20.0	19.5	20.5	23.7	19.9
Hydrogen, mass%**	13.84	13.82	13.52	13.76	13.82	13.66	13.59	13.50	13.38

*Data supplied with sample. Other data determined at AFLRL.
**Determined at AFWOL/POSF

TABLE A-1. PROPERTIES OF JP-5 SAMPLES (CONT'D)

Sample Code	AL-10975-T	AL-10990-T	AL-10992-T	AL-10993-T	AL-11038-T	AL-10802-T	AL-10755-T	AL-11133-T
Property:								
Gravity, °API	40.3*	38.1*	40.4	39.3*	44.1	42.9*	40.7	40.0
Density								
@ 15°C, kg/L	0.8232	0.8339	0.8228	0.8280	0.8054	0.8110	0.8213	0.8247
Cloud point, °C	-50	<-60	-57	-49	<-60	-53	-52	-52
Freezing point, °C	-48*	-59*	-	-49*	-	-50*	-49*	-
Flash point, °C	64*	69*	55	68*	56	62*	64*	64
Viscosity								
@ 40°C, cSt	1.5	1.7	1.4	1.6	1.3	1.4	1.6	1.6
Aniline point, °C (°F)	56.0 (132.8)	57.2 (134.9)	54.8 (130.6)	57.2 (135.0)	56.2 (133.2)	58.6 (137.5)	59.4 (139.0)	55.6 (132.1)
Cetane Number,								
D 613	42.9	37.6	40.3	43.1	40.8	45.1	40.1	41.9
Cetane Index,								
D 976-80	38.9	38.8	39.0	39.8	45.1	42.8	41.5	41.4
Sulfur, mass%	0.01*	0.14*	0.06	0.10*	0.03	0.01	<0.01	0.13
Distillation,								
D 86 (D 2887) °C								
IBP	180*(135)	182*(127)	180 (131)	186*(131)	176 (135)	184*(160)	187 (158)	191 (142)
10% recovered	193 (179)	200 (185)	197 (176)	200 (186)	192 (174)	195 (182)	198 (184)	204 (186)
20% recovered	198 (193)	206 (200)	200 (191)	205 (198)	196 (186)	197 (192)	201 (194)	208 (197)
50% recovered	209 (216)	219 (228)	209 (212)	216 (220)	207 (208)	207 (211)	213 (218)	217 (220)
90% recovered	234 (254)	244 (261)	226 (237)	242 (258)	228 (242)	230 (244)	250 (270)	239 (253)
FBP	250 (281)	260 (294)	256 (274)	266 (305)	247 (276)	257 (285)	273 (302)	257 (291)
Residue, vol%	1.0	1.0	0.5	1.3	1.0	1.0	1.0	1.0
Loss, vol%	0	0	0	0	0	0	0.1	0
Aromatics, FIA, vol%	21.8	20.9	21.2	22.6	25.0	19.1	20.2	22.8
Hydrogen, mass%**	13.42	13.44	13.44	13.41	13.71	13.80	13.61	13.37

*Data supplied with sample. Other data determined at AFLRL.
**Determined at AFWOL/POSF.

TABLE A-1. PROPERTIES OF JP-5 SAMPLES (CONT'D)

Sample Code	AL-10989-T	AL-10719-T	AL-10905-T	AL-10820-T	AL-11083-T	AL-10867-T
Property:						
Gravity, °API	38.3	42.8	41.4*	36.3*	43.5	39.1*
Density						
@ 15°C, kg/L	0.8329	0.8114	0.8180	0.8428	0.8082	0.8290
Cloud point, °C	< -60	-54	-49	< -60	-46	-49
Freezing point, °C	-	-56*	-47*	-57*	-46*	-46*
Flash point, °C	60	64	61*	71*	61	65*
Viscosity						
@ 40°C, cSt	1.7	1.4	1.5	1.7	1.4	1.6
Aniline point, °C (°F)	57.0 (134.6)	51.8 (125.2)	57.8 (136.0)	55.8 (132.4)	59.8 (139.6)	56.6 (133.9)
Cetane Number,						
D 613	39.1	40.8	40.8	35.3	47.5	42.3
Cetane Index,						
D 976-80	39.9	42.5	42.4	36.5	44.7	40.5
Sulfur, Mass%	0.14	0.13	0.11	0.04	0.05*	0.01
Distillation,						
D 86 (D 2887) °C)						
IBP	179 (124)	180 (142)	-* (121)	191* (142)	176* (140)	-* (169)
10% recovered	201 (183)	192 (173)	196 (177)	199 (183)	195 (181)	201 (202)
20% recovered	208 (198)	196 (186)	201 (194)	-- (198)	-- (193)	206 (213)
50% recovered	221 (226)	207 (213)	213 (215)	221 (228)	209 (215)	219 (242)
90% recovered	244 (260)	232 (251)	237 (252)	250 (268)	232 (251)	246 (279)
FBP	265 (292)	262 (279)	261 (294)	269 (301)	255 (273)	272 (304)
Residue, vol%	1.0	1.0	1.0	1.0	1.0	1.0
Loss, vol%	0	0	0	0	0	1.0
Aromatics, FIA, vol%	21.6	20.4	20.5	22.1	21.1	22.4
Hydrogen, mass%**	13.48	13.76	13.58	13.34	13.72	13.52***

*Data supplied with sample. Other data determined at AFLRL.
**Determined at AFWAL/POSF.
***AFLRL data.

TABLE A-2. PROPERTIES OF JET A SAMPLES

Sample Code	AL-10693-T	AL-10717-T	AL-10718-T	AL-10720-T	AL-10721-T	AL-10723-T	AL-10725-T	AL-10733-T	AL-10734-T
Property:									
Gravity, °API	42.1	42.7	41.0	43.9	42.8	45.0	41.6	42.4	43.9
Density									
@ 15°C, kg/L	0.8147	0.8119	0.8199	0.8064	0.8114	0.8017	0.8171	0.8133	0.8064
Cloud point, °C	-36	-47	-38	-44	-41	-46	-45	-50	-42
Freezing point, °C	-42*	-55*	-42*	-44*	-	-48*	-47*	-56*	-46*
Flash point, °C	60*	68*	52*	57*	48	52*	52*	59*	59*
Viscosity									
@ 40°C, cSt	1.6	1.5	1.6	1.4	1.5	1.3	1.4	1.3	1.6
Aniline point, °C (°F)	64.0*(147.2)	64.0*(147.2)	60.6 (141.1)	60.7 (141.3)	64.2 (147.6)	61.8 (143.2)	57.0 (134.6)	54.8 (130.6)	67.0 (152.6)
Cetane Number,									
D 613	47.8	42.5	42.5	43.8	46.8	45.0	42.1	42.9	48.4
Cetane Index,									
D 976-80	46.4	42.5	44.5	44.5	45.4	44.5	41.6	38.6	47.0
Sulfur, Mass%	0.06*	0.02*	0.02	0.03*	< 0.01	< 0.01	< 0.01	0.04	0.05
Distillation,									
D 86, (D 2887) °C									
IBP	171 (123)	189 (153)	163 (102)	172 (119)	144 (145)	168 (124)	168 (122)	177 (136)	178 (126)
10% recovered	193 (179)	200 (181)	183 (171)	189 (169)	200 (183)	183 (164)	188 (171)	188 (171)	194 (180)
20% recovered	200 (197)	202 (191)	200 (192)	193 (182)	204 (194)	188 (175)	194 (189)	191 (185)	200 (195)
50% recovered	220 (231)	210 (215)	221 (226)	207 (211)	214 (219)	201 (205)	210 (219)	200 (206)	213 (220)
90% recovered	259 (282)	234 (251)	255 (273)	240 (256)	243 (262)	235 (251)	235 (257)	222 (238)	248 (269)
FBP	289 (316)	269 (290)	286 (302)	272 (293)	281 (299)	276 (298)	273 (300)	261 (287)	282 (319)
Residue, vol%	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Loss, vol%	0	0	0	0	0	0	0	0	0
Aromatics, FIA, vol%	16.6	15.5	19.0	20.0	17.5	16.4	20.0	21.9	12.0
Hydrogen, mass%**	13.95	13.91	13.95	13.82	13.84	13.96	13.57	13.55	14.10

*Data supplied with sample. Other data determined at AFLRL.
**Determined at AFWAL/POSF

TABLE A-2. PROPERTIES OF JET A SAMPLES (CONT'D)

Sample Code	AL-10738-T	AL-10739-T	AL-10740-T	AL-10741-T	AL-10750-T	AL-10751-T	AL-10752-T	AL-10774-T	AL-10775-T
Property:									
Gravity, °API	42.7	44.4	44.2	41.8	44.3	45.8	44.7	48.4	42.6
Density @ 15°C, kg/L	0.8119	0.8041	0.8050	0.8161	0.8045	0.7977	0.8027	0.7862	0.8124
Cloud point, °C	-43	-37	-40	-35	-41	-40	-41	-56	-43
Freezing point, °C	-	-42*	-	-	-	-	-	-	-
Flash point, °C	55	52*	46	56	51*	52	43	47	56
Viscosity @ 40°C, cSt	1.5	1.5	1.4	1.6	1.3	1.4	1.4	1.1	1.5
Aniline point, °C (°F)	61.0 (141.8)	62.0*(143.6)	59.8 (139.6)	61.0 (141.8)	59.4 (138.9)	62.8 (145.0)	63.8 (146.8)	60.2 (140.4)	60.4 (140.7)
Cetane Number, D 613	44.5	47.2	47.8	49.0	42.9	47.8	46.6	42.9	44.6
Cetane Index, D 976-80	44.0	47.5	46.0	45.4	39.5	49.5	46.5	41.7	44.5
Sulfur, mass%	0.06	0.01	0.07	0.22	0.07*	0.07	0.03	< 0.01	< 0.01
Distillation, D 86, (D 2887) °C									
IBP	172 (143)	167 (118)	157 (101)	173 (112)	173 (152)	171 (130)	158 (95)	164 (128)	171 (131)
10% recovered	191 (193)	186 (167)	178 (158)	198 (180)	181 (169)	189 (187)	180 (163)	172 (160)	191 (192)
20% recovered	197 (207)	193 (184)	187 (174)	206 (197)	183 (176)	194 (201)	188 (174)	174 (170)	199 (208)
50% recovered	211 (236)	212 (217)	208 (213)	219 (226)	193 (197)	209 (228)	208 (213)	198 (190)	213 (231)
90% recovered	245 (280)	251 (269)	246 (266)	245 (267)	247 (264)	247 (279)	249 (266)	199 (217)	241 (272)
FBP	276 (317)	284 (317)	283 (314)	275 (302)	289 (326)	286 (333)	279 (316)	217 (245)	272 (319)
Residue, vol%	1.0	1.0	1.0	1.0	1.5	1.5	1.0	1.0	1.0
Loss, vol%	0	0	0	0	0	0	0	0	0.1
Aromatics, FIA, vol%	18.0	20.9	21.1	19.9	18.5	21.4	15.2	14.6	19.4
Hydrogen, mass%**	13.80	13.90	13.74	13.67	13.92	13.98	13.92	14.82	13.78

*Data supplied with sample. Other data determined at AFLRL.
**Determined at AFWAL/POSF.

TABLE A-2. PROPERTIES OF JET A SAMPLES (CONT'D)

Sample Code	AL-10776-T	AL-10777-T	AL-10778-T	AL-10779-T	AL-10793-T	AL-10798-T	AL-10800-T	AL-10801-T	AL-10821-T
Property:									
Gravity, °API	41.3	40.4	42.5	43.6	43.5*	39.0	43.0	40.0*	43.4
Density									
@ 15°C, kg/L	0.8185	0.8228	0.8128	0.8077	0.8082	0.8295	0.8105	0.8247	0.8087
Cloud point, °C	-41	-44	-40	-41	-41	-53	-38	-56	-37
Freezing point, °C	-44*	-44*	-45*	-	-	-	-	-52*	-
Flash point, °C	52*	59*	61*	57	58*	62	50	54*	54
Viscosity									
@ 40°C, cSt	1.7	1.6	1.5	1.6	1.6	1.5	1.5	1.5	1.5
Aniline Point, °C (°F)	64.0 (147.2)	59.0 (138.2)	61.0 (141.8)	68.5 (150.4)	67.0 (152.6)	53.2 (127.8)	61.2 (142.2)	54.9 (130.8)	62.4 (144.3)
Cetane Number,									
D 613	43.2	42.1	43.8	48.8	45.4	40.8	47.3	41.1	49.1
Cetane Index,									
D 976-80	46.5	42.5	42.5	47.0	48.9	38.1	46.5	38.3	48.0
Sulfur, mass%	0.01*	0.06*	0.01*	0.02	0.02*	< 0.01	0.02	< 0.01	< 0.01
Distillation,									
D 86 (D 2887) °C									
IBP	160 (113)	173 (128)	176 (133)	174 (113)	181*(135)	183 (145)	164 (118)	168*(121)	168 (118)
10% recovered	192 (173)	192 (174)	189 (171)	197 (181)	199 (178)	198 (177)	186 (169)	188 (177)	190 (169)
20% recovered	206 (200)	200 (194)	193 (184)	205 (199)	- (200)	200 (189)	193 (184)	- (195)	199 (191)
50% recovered	226 (230)	219 (227)	209 (213)	215 (222)	220 (225)	213 (215)	216 (220)	209 (218)	218 (223)
90% recovered	258 (275)	249 (269)	238 (256)	235 (253)	239 (256)	241 (256)	256 (272)	232 (252)	241 (256)
FBP	284 (319)	271 (307)	264 (300)	264 (292)	271 (284)	266 (291)	277 (307)	253 (285)	266 (291)
Residue, vol%	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.0
Loss, vol%	0	0.5	0.5	0	0	0	0	0	0
Aromatics, FIA, vol%	17.1	21.1	17.0	14.4	20.6	23.4	19.3	20.5	17.7
Hydrogen, mass%**	13.82	13.58	13.81	13.94	13.71	13.36	13.78	13.52	13.92

*Data supplied with sample. Other data determined at AFLRL.
**Determined at AFWAL/POSF.

TABLE A-2. PROPERTIES OF JET A SAMPLES (CONT'D)

Sample Code	AL-10895-T	AL-10893-T	AL-10894-T	AL-10946-T	AL-10819-T	AL-10904-T	AL-10998-T	AL-10868-T
Property:								
Gravity, °API	41.2*	43.6	43.8*	44.4	37.9*	44.9	42.0	43.0*
Density @ 15°C, kg/L	0.8189	0.8077	0.8068	0.8041	0.8349	0.8018	0.8152	0.8105
Cloud point, °C	-52	-42	-50	-40	< -60	-50	-40	-40
Freezing point, °C	-49*	-	-43*	-	-59*	-	-	-42*
Flash point, °C	57	51	52*	49	63*	46	56	62*
Viscosity @ 40°C, cSt	1.6	1.4	1.4	1.5	1.6	1.2	1.6	1.5
Aniline point, °C (°F)	58.6 (137.5)	62.2 (144.0)	60.4 (140.7)	63.4 (146.1)	55.7 (132.3)	55.8 (132.4)	61.8 (143.2)	62.2 (144.0)
Cetane Number, D 613	45.1	48.6	45.4	50.1	36.3	42.7	45.1	51.9
Cetane Index, D 976-80	42.4	44.5	44.5	48.0	35.8	40.5	46.1	46.9
Sulfur, mass%	0.10*	0.06	0.06*	0.11	0.01*	0.09	< 0.01	0.11*
Distillation, D 86 (D 2887) °C								
IBP	174*(140)	167 (145)	170*(89)	163 (108)	193* (154)	159 (113)	174 (113)	-* (123)
10% recovered	194 (201)	183 (177)	183 (162)	188 (169)	199 (184)	177 (163)	198 (184)	194 (176)
20% recovered	- (213)	190 (189)	- (179)	194 (187)	- (194)	181 (173)	207 (196)	- (191)
50% recovered	214 (239)	208 (215)	207 (210)	213 (216)	212 (215)	193 (196)	220 (224)	217 (220)
90% recovered	242 (276)	253 (255)	252 (263)	247 (264)	234 (248)	221 (235)	247 (263)	249 (264)
FBP	262 (305)	281 (291)	280 (309)	273 (312)	253 (287)	250 (286)	267 (302)	272 (297)
Residue, vol%	1.0	1.5	1.0	1.5	1.0	1.0	1.0	1.0
Loss, vol%	0	0	0	0	0	0	0	0
Aromatics, FIA, vol%	22.7	17.1	17.5	18.0	17.1	20.2	19.4	20.2
Hydrogen, mass%**	13.62	13.88	13.82	13.92	13.49	13.78	13.68	13.82

*Data supplied with sample. Other data determined at AFLRL.
**Determined at AFWAL/POSF.

TABLE A-3. PROPERTIES OF JET A-1 SAMPLES

Sample Code	AL-10795-T	AL-10877-T	AL-10903-T	AL-10947-T	AL-10948-T	AL-10991-T	AL-11082-T	AL-10892-T	AL-10891-T
Property:									
Gravity, °API	44.1	44.1	44.0	47.9	49.3*	41.3	47.5	42.8	43.5
Density									
@ 15°C, kg/L	0.8054	0.8054	0.8059	0.7884	0.7823	0.8185	0.7902	0.8114	0.8082
Cloud point, °C	-50	-45	< -60	-49	< -60	< -60	-49	-50	-46
Freezing point, °C	-49*	-49*	-60*	-51*	-61*	-	-50*	-49*	-
Flash point, °C	50*	48*	51	40*	41*	36	40*	40*	40
Viscosity									
@ 40°C, cSt	1.3	1.3	1.3	1.2	1.0	1.3	1.2	1.4	1.4
Aniline point, °C (°F)	57.2 (135.0)	59.6 (139.3)	56.8 (134.2)	60.6 (141.0)	58.9 (138.0)	54.6 (130.3)	61.3 (142.3)	56.6 (133.9)	59.2 (138.6)
Cetane Number,									
D 613	41.4	44.8	39.9	48.1	44.3	34.7	44.7	42.4	43.5
Cetane Index,									
D 976-80	41.5	43.4	41.1	46.0	43.5	38.2	47.0	43.4	46.3
Sulfur, mass%	0.03	0.02*	0.01	0.16	0.14*	0.08	0.09*	0.01	0.05
Distillation,									
D 86, (D 2887) °C									
IBP	156 (108)	-* (104)	-* (133)	148* (95)	150* (96)	149 (89)	148* (98)	-* (89)	147 (88)
10% recovered	175 (156)	182 (165)	183 (165)	166 (150)	167 (156)	174 (158)	166 (152)	177 (158)	180 (160)
20% recovered	181 (169)	- (176)	- (175)	- (166)	- (167)	183 (172)	- (167)	- (176)	191 (178)
50% recovered	199 (203)	203 (208)	198 (198)	192 (197)	181 (186)	203 (207)	196 (198)	209 (212)	213 (215)
90% recovered	236 (252)	239 (253)	233 (246)	231 (251)	202 (217)	238 (253)	233 (251)	241 (258)	242 (258)
FBP	259 (279)	257 (301)	269 (303)	257 (302)	224 (249)	273 (316)	247 (276)	260 (290)	262 (294)
Residue, vol%	1.0	1.0	1.0	1.0	0.5	1.5	1.0	1.0	1.0
Loss, vol%	0	0	0	0	0	0	0	0	0
Aromatics, FIA, vol%	20.2	18.5	19.5	19.6	18.1	19.0	19.0	21.0	19.3
Hydrogen, mass%**	13.74	13.86	13.78	14.04	14.12	13.62	13.99	13.67	13.78

*Data supplied with sample. Other data determined at AFLRL.
**Determined at AFWAL/POSF.

IDENTIFICATION OF JP-5 SAMPLES

AL-Code Number	Company	Refinery Location
10780	Exxon	Baton Rouge, LA
10794	Gulf	Port Arthur, TX
10786	Mobil	Beaumont, TX
10865	Shell	Deer Park, TX
10869	K.N.P.C.	Shuaiba, Kuwait
10866	Exxon	Benicia, CA
10878	U.S. Oil and Refining	Tacoma, WA
10900	Douglas Oil	Paramount, CA
10972	Mobil	Torrance, CA
10975	Hawaiian Independent Refining	Oahu, HI
10990	Exxon Int'l	Aruba, Netherland Antilles
10992	Beacon Oil	Hanford, CA
10993	Fletcher Oil	Carson, CA
11038		Sigonella, Italy
10802	Hess Oil	St. Croix, USVI
10755	Arco	Ferndale, WA
11133	Powerine Oil	Santa Fe, CA
10989	Exxon Int'l	Aruba, Netherland Antilles
10719	Shell	Deer Park, TX
10905	Imperial Oil Ltd.	Dartmouth, Nova Scotia
10820	Mobil	Torrance, CA
11083	Imperial Oil Ltd.	Fawley, Great Britain
10867	Mobil	Beaumont, TX

IDENTIFICATION OF JET-A SAMPLES

AL-Code Number	Company	Refinery Location
10693	Conoco	Ponca City, OK
10717	Conoco	West Lake, LA
10718	Shell	Norco, LA
10720	Phillips	Borger, TX
10721	Phillips	Sweeney, TX
10723	Phillips	Kansas City, KA
10725	Arco	Carson, CA
10733	Mobil	Ferndale, WA
10734	Mobil	Augusta, GA
10738	Texaco	Tulsa, OK
10739	Texaco	Convent, LA
10740	Amoco	Mandan, ND
10741	Amoco	Whiting, IN
10750	Texaco	Casper, WY
10751	Mobil	Paulsboro, NJ
10752	Tenneco	Chalmette, LA
10774	Phillips	Bartlesville, OK
10775	Texaco	Lawrenceville, IL
10776	Gulf	Alliance, LA
10777	Gulf	Port Arthur, TX
10778	Gulf	Philadelphia, PA
10779	Union	Rodeo, CA
10793	Union	Beaumont, TX
10798	Union	Los Angeles, CA
10800	Texaco	Port Arthur, TX
10801	Union	San Francisco, CA
10821	Texaco	Anacortes, WA
10895	Conoco	Billings, MT
10893	Boron	Lima, OH
10894	Sohio	Toledo, OH
10946	Citgo	Tulsa, OK
10819	Mobil	Torrance, LA
10904	Imperial Oil	Dartmouth, Nova Scotia
10998	British Petroleum	Marcus Hook, PA
10868	Mobil	Beaumont, TX

IDENTIFICATION OF JET A-1 SAMPLES

AL-Code Number	Company	Refinery Location
10795	Imperial Oil	Ontario, Canada
10877	Shell Canada	Shelburne, B.C., Canada
10903	Shell Canada	Montreal, Canada
10947	Caltex	Awali, Baharain
10948	Caltex	Seoul, Korea
10991	Exxon Int'l	Aruba, Netherland Antilles
11082	Imperial Oil	Fawley, Great Britain
10892	Shell Canada	Oakville, B.C., Canada
10891	Imperial Oil	Quebec, Canada

APPENDIX B

BLENDING CORRELATIONS

TABLE B-1. REID VAPOR PRESSURE BLENDING INDEX NUMBERS FOR GASOLINES AND TURBINE FUELS

Vapor Pressure, psi	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.05	0.13	0.22	0.31	0.42	0.52	0.64	0.75	0.87
1	1.00	1.12	1.25	1.38	1.52	1.66	1.79	1.94	2.08	2.23
2	2.37	2.52	2.67	2.83	2.98	3.14	3.30	3.46	3.62	3.78
3	3.94	4.11	4.28	4.44	4.61	4.78	4.95	5.13	5.30	5.48
4	5.65	5.83	6.01	6.19	6.37	6.55	6.73	6.92	7.10	7.29
5	7.47	7.66	7.85	8.04	8.23	8.42	8.61	8.80	9.00	9.19
6	9.39	9.58	9.78	9.98	10.2	10.4	10.6	10.8	11.0	11.2
7	11.4	11.6	11.8	12.0	12.2	12.4	12.6	12.8	13.0	13.2
8	13.4	13.7	13.9	14.1	14.3	14.5	14.7	14.9	15.2	15.4
9	15.6	15.8	16.0	16.2	16.4	16.7	16.9	17.1	17.3	17.6
10	17.8	18.0	18.2	18.4	18.7	18.9	19.1	19.4	19.6	19.8
11	20.0	20.3	20.5	20.7	20.9	21.2	21.4	21.6	21.9	22.1
12	22.3	22.6	22.8	23.0	23.3	23.5	23.7	24.0	24.2	24.4
13	24.7	24.9	25.2	25.4	25.6	25.9	26.1	26.4	26.6	26.8
14	27.1	27.3	27.6	27.8	28.0	28.3	28.5	28.8	29.0	29.3
15	29.5	29.8	30.0	30.2	30.5	30.8	31.0	31.2	31.5	31.8
16	32.0	32.2	32.5	32.8	33.0	33.2	33.5	33.8	34.0	34.3
17	34.5	34.8	35.0	35.3	35.5	35.8	36.0	36.3	36.6	36.8
18	37.1	37.3	37.6	37.8	38.1	38.4	38.6	38.9	39.1	39.4
19	39.7	39.9	40.2	40.4	40.7	41.0	41.2	41.5	41.8	42.0
20	42.3	42.6	42.8	43.1	43.4	43.6	43.9	44.2	44.4	44.7
21	45.0	45.2	45.5	45.8	46.0	46.3	46.6	46.8	47.1	47.4
22	47.6	47.9	48.2	48.4	48.7	49.0	49.3	49.5	49.8	50.1
23	50.4	50.6	50.9	51.2	51.5	51.7	52.0	52.3	52.6	52.8
24	53.1	53.4	53.7	54.0	54.2	54.5	54.8	55.1	55.3	55.6
25	55.9	56.2	56.5	56.7	57.0	57.3	57.5	57.9	58.1	58.4
26	58.7	59.0	59.3	59.6	59.8	60.1	60.4	60.7	61.0	61.3
27	61.5	61.8	62.1	62.4	62.7	63.0	63.3	63.5	63.8	64.1
28	64.4	64.7	65.0	65.3	65.6	65.8	66.1	66.4	66.7	67.0
29	67.3	67.6	67.9	68.2	68.4	68.8	69.0	69.3	69.6	69.9
30	70.2									
40	101									
(nC_4) 51.6	138									
(iC_4) 72.2	210									
(C_3) 190	705									

Equation:

$$VPBI = VP^{1.25}$$

Example:

Calculate the vapor pressure of a gasoline blend as follows:

Component	Volume Fraction	Vapor Pressure, psi	Vapor Pressure Blending Index No.	Volume Fraction x VPBI
n-Butane	0.050	51.6	138	6.90
Light Straight Run	0.450	6.75	10.9	4.90
Heavy Refined	0.500	1.00	1.00	0.50
Total	1.000	7.4	12.3	12.30

Source: Gary and Handwerk (13)

TABLE B-2. VISCOSITY BLENDING INDEX NUMBERS

FACTORS FOR VOLUME BLENDING OF VISCOSITIES AT CONSTANT TEMPERATURE CORRESPONDING TO VALUES OF KINEMATIC VISCOSITY

Centistokes	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.5	0.000	0.006	0.013	0.019	0.025	0.030	0.036	0.041	0.046	0.051
0.6	0.056	0.061	0.065	0.069	0.074	0.078	0.082	0.086	0.089	0.093
0.7	0.097	0.100	0.104	0.107	0.110	0.114	0.117	0.120	0.123	0.126
0.8	0.128	0.131	0.134	0.137	0.139	0.142	0.144	0.147	0.149	0.152
0.9	0.154	0.156	0.159	0.161	0.163	0.165	0.167	0.169	0.172	0.174
cSt	**0.0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
1	0.176	0.194	0.210	0.224	0.236	0.247	0.257	0.266	0.275	0.283
2	0.290	0.297	0.303	0.309	0.314	0.320	0.325	0.329	0.334	0.338
3	0.342	0.346	0.350	0.353	0.357	0.360	0.363	0.366	0.369	0.372
4	0.375	0.379	0.380	0.383	0.385	0.387	0.390	0.392	0.394	0.396
5	0.398	0.400	0.402	0.404	0.406	0.409	0.410	0.411	0.413	0.414
6	0.416	0.418	0.419	0.421	0.422	0.423	0.425	0.426	0.428	0.429
7	0.431	0.432	0.433	0.434	0.436	0.437	0.438	0.439	0.440	0.442
8	0.443	0.444	0.445	0.446	0.447	0.448	0.449	0.450	0.451	0.452
9	0.453	0.454	0.455	0.456	0.456	0.457	0.458	0.459	0.460	0.461
cSt	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
10	0.462	0.470	0.477	0.493	0.499	0.494	0.499	0.503	0.508	0.511
20	0.515	0.519	0.522	0.525	0.529	0.531	0.533	0.536	0.538	0.541
30	0.543	0.545	0.547	0.549	0.551	0.553	0.555	0.557	0.558	0.559
40	0.561	0.563	0.564	0.566	0.567	0.568	0.570	0.571	0.572	0.573
50	0.575	0.576	0.577	0.578	0.579	0.580	0.581	0.582	0.583	0.584
60	0.585	0.586	0.587	0.588	0.589	0.590	0.591	0.592	0.592	0.593
70	0.594	0.595	0.596	0.596	0.597	0.598	0.599	0.599	0.600	0.601
80	0.601	0.602	0.603	0.603	0.604	0.605	0.605	0.606	0.607	0.607
90	0.608	0.608	0.609	0.610	0.610	0.611	0.611	0.612	0.612	0.613
cSt	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
100	0.613	0.618	0.623	0.627	0.631	0.634	0.637	0.640	0.643	0.646
200	0.648	0.651	0.653	0.655	0.657	0.659	0.661	0.662	0.664	0.666
300	0.667	0.669	0.670	0.671	0.673	0.674	0.675	0.676	0.678	0.679
400	0.680	0.681	0.682	0.683	0.684	0.685	0.686	0.687	0.688	0.688
500	0.689	0.690	0.691	0.692	0.692	0.693	0.694	0.695	0.696	0.696
600	0.697	0.698	0.698	0.699	0.700	0.700	0.701	0.701	0.702	0.702
700	0.703	0.704	0.704	0.705	0.705	0.706	0.706	0.707	0.707	0.708
800	0.708	0.709	0.709	0.710	0.710	0.711	0.711	0.712	0.712	0.713
900	0.713	0.714	0.714	0.715	0.715	0.715	0.716	0.716	0.716	0.717
cSt	**0**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**
1,000	0.717	0.721	0.724	0.727	0.730	0.733	0.735	0.737	0.739	0.741
2,000	0.743	0.745	0.747	0.748	0.750	0.751	0.752	0.754	0.755	0.756
3,000	0.757	0.758	0.759	0.761	0.762	0.763	0.764	0.765	0.765	0.766
4,000	0.767	0.768	0.769	0.770	0.770	0.771	0.772	0.772	0.773	0.774
5,000	0.775	0.775	0.776	0.777	0.778	0.778	0.778	0.779	0.779	0.780
6,000	0.780	0.781	0.781	0.782	0.782	0.783	0.783	0.784	0.784	0.785
7,000	0.785	0.786	0.786	0.787	0.787	0.787	0.788	0.788	0.789	0.790
8,000	0.790	0.790	0.790	0.791	0.791	0.791	0.792	0.792	0.792	0.793
9,000	0.793	0.794	0.794	0.794	0.795	0.795	0.795	0.796	0.796	0.796
cSt	**0**	**1000**	**2000**	**3000**	**4000**	**5000**	**6000**	**7000**	**8000**	**9000**
10,000	0.796	0.799	0.802	0.804	0.806	0.808	0.810	0.812	0.814	0.815
20,000	0.817	0.818	0.820	0.821	0.822	0.823	0.824	0.825	0.826	0.827
30,000	0.828	0.829	0.830	0.831	0.832	0.833	0.833	0.834	0.835	0.836
40,000	0.836	0.837	0.838	0.838	0.839	0.839	0.840	0.841	0.841	0.842
50,000	0.842	0.843	0.843	0.844	0.844	0.845	0.845	0.846	0.846	0.847
60,000	0.847	0.848	0.849	0.848	0.849	0.849	0.850	0.850	0.850	0.851
70,000	0.851									
80,000	0.854									
90,000	0.858									

cSt	
100,000	0.860
200,000	0.877
300,000	0.887
400,000	0.894
500,000	0.899
600,000	0.903
700,000	0.906
800,000	0.909
900,000	0.912
cSt	
1,000,000	0.914
2,000,000	0.928
3,000,000	0.937
4,000,000	0.942
5,000,000	0.947
6,000,000	0.950
7,000,000	0.953
8,000,000	0.956
9,000,000	0.958
cSt	
10,000,000	0.960
20,000,000	0.973
30,000,000	0.980
40,000,000	0.985
50,000,000	0.989
60,000,000	0.992
70,000,000	0.995
80,000,000	0.997
90,000,000	0.999

Example: Calculate the viscosity of a three-component blend as follows:

Component	Vol. Fraction in Blend	Viscosity	Factor	Vol. Fraction x Factor
A	0.5	430 SFS at 122°F	0.700	0.350
B	0.3	92.5 SUS at 130°F	0.500	0.150
C	0.2	2.15 cSt at 130°F	0.300	0.060
Total	1.0	(39.5 cSt at 130°F) (or 193 SUS at 130°F) (or 26 SFS at 122°F)	(0.560)	0.560

FACTORS FOR VOLUME BLENDING OF VISCOSITIES AT CONSTANT TEMPERATURE CORRESPONDING TO VALUES OF SAYBOLT UNIVERSAL SECONDS

SUS	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
32	0.275	0.278	0.280	0.282	0.284	0.286	0.288	0.290	0.292	0.294
33	0.296	0.298	0.300	0.302	0.303	0.305	0.307	0.309	0.310	0.312
34	0.314	0.315	0.317	0.318	0.320	0.321	0.323	0.324	0.326	0.327
35	0.329	0.330	0.331	0.333	0.334	0.335	0.337	0.338	0.339	0.340
36	0.342	0.343	0.344	0.345	0.346	0.347	0.349	0.350	0.351	0.352
37	0.353	0.354	0.355	0.356	0.357	0.358	0.359	0.360	0.362	0.363
38	0.363	0.364	0.365	0.366	0.367	0.368	0.369	0.370	0.371	0.372
39	0.373	0.373	0.374	0.375	0.376	0.377	0.378	0.379	0.379	0.380
SUS	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
40	0.381	0.388	0.395	0.402	0.408	0.413	0.418	0.423	0.428	0.431
50	0.435	0.439	0.442	0.445	0.449	0.451	0.454	0.457	0.459	0.462
60	0.464	0.466	0.469	0.471	0.473	0.475	0.476	0.478	0.480	0.482
70	0.483	0.485	0.486	0.488	0.489	0.491	0.492	0.493	0.495	0.496
80	0.497	0.498	0.499	0.501	0.502	0.503	0.504	0.505	0.506	0.507
90	0.508	0.509	0.510	0.511	0.512	0.513	0.513	0.514	0.515	0.516
SUS	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
100	0.517	0.524	0.531	0.537	0.542	0.547	0.551	0.555	0.559	0.562
200	0.565	0.568	0.571	0.574	0.576	0.579	0.581	0.583	0.585	0.587
300	0.589	0.591	0.593	0.595	0.596	0.598	0.600	0.601	0.603	0.604
400	0.605	0.607	0.608	0.609	0.611	0.612	0.613	0.614	0.615	0.616
500	0.617	0.618	0.619	0.620	0.621	0.622	0.623	0.624	0.625	0.626
600	0.627	0.628	0.628	0.629	0.630	0.631	0.632	0.632	0.633	0.634
700	0.635	0.635	0.636	0.637	0.637	0.638	0.639	0.639	0.640	0.640
800	0.641	0.642	0.642	0.643	0.643	0.644	0.645	0.645	0.646	0.646
900	0.647	0.647	0.648	0.648	0.649	0.649	0.650	0.650	0.651	0.651
SUS	**0**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**
1,000	0.652	0.656	0.660	0.664	0.667	0.670	0.673	0.676	0.678	0.681
2,000	0.683	0.685	0.687	0.689	0.691	0.692	0.694	0.696	0.697	0.699
3,000	0.700	0.701	0.703	0.704	0.705	0.706	0.707	0.708	0.709	0.710
4,000	0.711	0.712	0.713	0.714	0.715	0.716	0.717	0.718	0.719	0.719
5,000	0.720	0.721	0.722	0.722	0.723	0.724	0.725	0.725	0.726	0.726
6,000	0.727	0.728	0.728	0.729	0.729	0.730	0.731	0.731	0.732	0.732
7,000	0.733	0.733	0.734	0.734	0.735	0.735	0.736	0.736	0.737	0.737
8,000	0.738	0.738	0.739	0.739	0.740	0.740	0.740	0.741	0.741	0.742
9,000	0.742	0.742	0.743	0.743	0.744	0.744	0.744	0.745	0.745	0.745
SUS	**0**	**1000**	**2000**	**3000**	**4000**	**5000**	**6000**	**7000**	**8000**	**9000**
10,000	0.746	0.749	0.752	0.755	0.758	0.760	0.762	0.764	0.766	0.768
20,000	0.770	0.771	0.773	0.774	0.776	0.777	0.778	0.779	0.781	0.782
30,000	0.783	0.784	0.785	0.786	0.787	0.788	0.789	0.790	0.790	0.791
40,000	0.792	0.793	0.793	0.794	0.795	0.795	0.796	0.797	0.797	0.798
50,000	0.799	0.799	0.800	0.800	0.801	0.802	0.802	0.803	0.803	0.804
60,000	0.804	0.805	0.805	0.806	0.806	0.807	0.807	0.807	0.808	0.808

SUS	
70,000	0.809
80,000	0.813
90,000	0.816
SUS	
100,000	0.819
200,000	0.838
300,000	0.849
400,000	0.856
500,000	0.862
600,000	0.867
700,000	0.870
800,000	0.874
900,000	0.877
SUS	
1,000,000	0.879
2,000,000	0.895
3,000,000	0.904
4,000,000	0.911
5,000,000	0.915
6,000,000	0.919
7,000,000	0.923
8,000,000	0.925
9,000,000	0.928
SUS	
10,000,000	0.930
20,000,000	0.944
30,000,000	0.952
40,000,000	0.957
50,000,000	0.961
60,000,000	0.965
70,000,000	0.968
80,000,000	0.970
90,000,000	0.972

FACTORS FOR VOLUME BLENDING OF VISCOSITIES AT 130°F CORRESPONDING TO VALUES OF SAYBOLT FUROL SECONDS AT 122°F

SFS at 122°F	0	1	2	3	4	5	6	7	8	9
20						0.558	0.561	0.563	0.566	0.568
30	0.570	0.572	0.574	0.576	0.578	0.580	0.582	0.584	0.585	0.587
40	0.588	0.590	0.591	0.593	0.594	0.595	0.597	0.598	0.599	0.600
50	0.601	0.602	0.604	0.605	0.606	0.607	0.608	0.609	0.610	0.610
60	0.611	0.612	0.613	0.614	0.615	0.616	0.616	0.617	0.618	0.619
70	0.619	0.620	0.621	0.622	0.622	0.623	0.624	0.624	0.625	0.626
80	0.626	0.627	0.627	0.628	0.629	0.629	0.630	0.630	0.631	0.632
90	0.632	0.633	0.633	0.634	0.634	0.635	0.635	0.636	0.636	0.637
SFS at 122°F	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
100	0.637	0.642	0.646	0.649	0.653	0.656	0.659	0.661	0.664	0.666
200	0.669	0.671	0.673	0.675	0.676	0.678	0.680	0.681	0.683	0.684
300	0.686	0.687	0.688	0.689	0.691	0.692	0.693	0.694	0.695	0.696
400	0.697	0.698	0.699	0.700	0.701	0.702	0.703	0.703	0.704	0.705
500	0.706	0.707	0.707	0.708	0.709	0.710	0.710	0.711	0.712	0.712
600	0.713	0.713	0.714	0.715	0.715	0.716	0.716	0.717	0.718	0.719
700	0.719	0.719	0.720	0.720	0.721	0.721	0.722	0.722	0.723	0.723
800	0.724	0.724	0.724	0.725	0.725	0.726	0.726	0.727	0.727	0.727
900	0.728	0.728	0.729	0.729	0.729	0.730	0.730	0.730	0.731	0.731
SFS at 122°F	**0**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**
1,000	0.732	0.735	0.738	0.741	0.743	0.746	0.748	0.750	0.752	0.754
2,000	0.755	0.757	0.759	0.760	0.761	0.763	0.764	0.766	0.766	0.767
3,000	0.769	0.770	0.771	0.772	0.773	0.773	0.774	0.775	0.776	0.777
4,000	0.778									
5,000	0.784									
6,000	0.790									
7,000	0.795									
8,000	0.798									
9,000	0.802									

Note: Values from this table are for 130°F, although the Saybolt Furol seconds are at 122°F. This table alone must not be used for any other temperatures. Values from this table may be used interchangeably with values for kinematic and Saybolt Universal viscosities if the latter are for 130°F.

For SFS at 210°F, assume SUS = 10 x SFS and use the Saybolt Universal table.

Source: Gary and Handwerk (10)

TABLE B-3. POUR POINT BLENDING INDICES FOR DISTILLATE STOCKS

ASTM 50% Temp / Pour Point	300	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700
70	133	131	129	128	127	125	123	120	118	115	113	110	108	105	103	100
65	114	111	109	107	105	103	101	98	96	94	91	88	85	82	79	76
60	99	94	92	90	87	85	82	80	77	74	72	69	67	64	62	60
55	88	79	77	75	73	71	68	66	63	61	58	56	53	50	48	46
50	72	68	66	63	61	59	56	54	52	49	47	44	42	39	37	35
45	60	56	54	52	50	48	46	44	42	40	38	35	33	31	29	27
40	52	48	46	44	42	40	38	36	34	32	30	28	26	24	22	21
35	44	41	39	37	35	33	32	30	28	26	24	23	21	19	18	16
30	37	34	32	31	29	27	26	24	23	21	19	18	16	15	14	13
25	32	29	27	26	24	23	21	20	18	17	15	14	13	12	11	10
20	27	24	23	21	20	19	17	16	15	14	12	11	10	9.1	8.3	7.5
15	23	20	19	18	17	16	14	13	12	11	10	9.0	8.1	7.2	6.4	5.8
10	20	17	16	15	14	13	12	11	9.8	8.8	8.0	7.1	6.3	5.6	5.0	4.5
5	17	15	14	13	12	11	9.7	8.8	7.9	7.1	6.3	5.6	5.0	4.4	3.8	3.5
0	14	12	11	10	9.6	8.7	7.9	7.1	6.3	5.6	5.0	4.4	3.8	3.4	3.0	2.7
-5	12	10	9.5	8.7	8.0	7.2	6.5	5.8	5.1	4.5	3.9	3.4	3.0	2.7	2.4	2.1
-10	10	8.8	8.0	7.3	6.6	5.9	5.3	4.7	4.1	3.6	3.2	2.8	2.5	2.2	1.9	1.6
-15	8.8	7.4	6.8	6.1	5.5	4.9	4.4	3.9	3.4	3.0	2.6	2.2	1.9	1.7	1.4	1.2
-20	7.5	6.3	5.7	5.1	4.6	4.1	3.6	3.2	2.8	2.4	2.1	1.8	1.5	1.3	1.1	0.94
-25	6.4	5.3	4.7	4.2	3.7	3.3	2.9	2.5	2.2	1.9	1.7	1.4	1.2	1.0	0.90	0.72
-30	5.5	4.5	4.0	3.6	3.2	2.8	2.4	2.1	1.8	1.5	1.3	1.1	0.96	0.80	0.67	0.56
-35	4.6	3.7	3.3	2.9	2.6	2.3	2.0	1.7	1.4	1.2	1.0	0.90	0.75	0.62	0.51	0.43
-40	4.0	3.2	2.8	2.5	2.2	1.9	1.6	1.4	1.2	1.0	0.86	0.73	0.62	0.51	0.41	0.33
-45	3.3	2.7	2.4	2.1	1.8	1.5	1.3	1.1	0.98	0.82	0.68	0.58	0.48	0.38	0.31	0.25
-50	2.8	2.3	2.0	1.7	1.5	1.3	1.1	0.93	0.78	0.66	0.56	0.47	0.38	0.31	0.25	0.20
-55	2.5	1.9	1.7	1.4	1.2	1.1	0.90	0.77	0.65	0.55	0.46	0.37	0.30	0.24	0.19	0.15
-60	2.1	1.6	1.4	1.2	1.0	0.87	0.74	0.62	0.52	0.43	0.36	0.30	0.24	0.19	0.14	0.10
-65	1.8	1.4	1.2	1.0	0.85	0.72	0.60	0.50	0.41	0.34	0.28	0.23	0.18	0.14	0.10	0.07
-70	1.5	1.1	0.99	0.84	0.71	0.60	0.50	0.42	0.36	0.30	0.25	0.20	0.15	0.11	0.08	0.05

To find the pour point of a blend, determine the index of each component from the table above. Compute the weighted arithmetic average index for the blend (i.e., blend indices straight line) and find the pour point corresponding to the blend index and blend 50 percent temperature from the table. Determine the 50 percent temperature of the blend by weighted arithmetic averaging.

Source: Reid and Allen (15)

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